A LABORATORY MANUAL

—OF—

PHYSICS

By
C. E. LINEBARGER

D. C. HEATH & CO., Publishers
BOSTON NEW YORK CHICAGO

A LABORATORY MANUAL

OF

PHYSICS

For Use in Secondary Schools

BY

C. E. LINEBARGER

Instructor in Physics in the Lake View High School, Chicago

[1911]

D. C. HEATH & CO., PUBLISHERS

BOSTON NEW YORK CHICAGO

1A3

CONTENTS

PREFACE

This Manual is a laboratory guide for the student.* While primarily planned to be used in connection with the author's Text-book of Physics with which it is closely correlated, it can be used with any other text or even with no text at all, as the discussions and explanations which it contains, when supplemented by the oral instruction of a live teacher, render the book independent of any text-book aid. Only such experiments are included as can be performed by large classes with a minimum tax on a teacher's time and energy. The number of experiments is large enough to permit some variation of work from year to year and to allow considerable latitude of choice. An equitable proportion of quantitative and qualitative experiments has been maintained throughout the course.

To prevent the student from slavishly following the directions, with his mind more or less hazy as to the whys and wherefores of what he is doing, discussions and explanations are introduced where needed, and a distinct statement of the object of each part of an experiment is given. The student thereby has put before him the precise thing he is after as well as the general course of his work. The list of apparatus needed as well as particulars about its arrangement and construction are given so that the student may be sure that he has what is required before he begins an experiment. The directions for manipulation are full enough to insure success, but wordiness and involved constructions are avoided. Here and there questions are inserted to stimulate thought, care being taken that they do not contain their own answer. The general form of the directions is such as will enable the experimenter to carry enough of them in mind so that he may devote his entire attention to the apparatus and will not work with one eye on the book and the other on the instruments. Many of the experiments have optional parts appended, the purpose being to keep the more rapid workers of a class busy, this being especially desirable if all of a class are engaged upon the same experiment at the same time.

The apparatus recommended is such as will not only give results of satisfactory accuracy but will also require a minimum of preliminary adjustment and will stand hard usage. The author has no patience with those teachers or school boards to whom the main recommendation of a piece of apparatus is its cheapness. While in some cases cheap apparatus may not necessarily be poor apparatus, yet all too often cheaply constructed pieces not only fail to give satisfactory results but also fail to stand more than a season or so of use. It always proves more economical in the end to provide well constructed apparatus built to last and not merely to sell.

* A Teacher's Handbook has been prepared to accompany the Manual. It may be obtained upon application to the publishers.

In order to reduce the cost of an outfit and yet to use none but the best of apparatus, it has been the aim in this course to make, wherever feasible, one good piece of apparatus active in several experiments. A $5.00 general utility board, for example, is a very expensive instrument if used in but a single experiment; but if it is made an important accessory in more than a dozen experiments, it must be regarded as a cheap piece of apparatus. The author has designed several pieces of apparatus especially for this course which may be used to advantage in so many experiments that the total cost of an equipment of good apparatus is very materially reduced.*

The loose-leaf form of this book has been adopted because it alone has the flexibility that enables the teacher to solve satisfactorily the note-book problem. It may be used just like the ordinary bound book, or the directions may be removed and bound up in a loose-leaf note-book cover† together with the results of the experiment. Loose-leaf methods have proved their practical worth in the business world, and only a trial is needed to convince one of their points of superiority in laboratory instruction.

* These special pieces are manufactured by the Chicago Apparatus Company, 557 West Quincy Street, Chicago. A list of the apparatus used in this Manual together with prices is given in Appendix C.

† The "No. 246" note-book cover and paper furnished by the Atlas School Supply Co., of Chicago, is recommended as being well adapted to be used in connection with the Manual.

EXPERIMENT I

LENGTH MEASUREMENTS

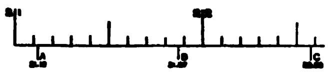
What to use. Metric rule (meter stick) and circular disk.

To measure the diameter and the circumference of a circle and to compute their ratio.

What to do. (1) Place the metric rule edgewise across the disk along a diameter so that some line on it lies even with the disk's edge. Do not measure from the end of the rule as it may be worn away. Count up the number of centimeters and tenths thereof (millimeters) until the opposite edge of the disk is reached. If this edge does not coincide with any line on the scale, estimate the tenths of a millimeter.

Estimation of Tenths. It is rare that both ends of a length coincide with lines marked on the scale. For example, line *A* in the figure lies between the 32d and the 33d mark. It is easy to estimate with the eye that the line *A* is about one-third of a scale division from the 32d mark, and the measurement is more accurate if expressed as 32.3 than if 32 (the nearest whole division) is taken. The eye readily learns to estimate tenths of a scale division with no greater an error than one or two tenths, while, if readings are not made closer than to the nearest whole division, the error may amount to as much as three or four, or even five, tenths of a division.

THE READING AT A IS 32.3



THE READING AT A IS 21.12; AT B, 21.87; AND AT C, 22.58

Proper Way of Expressing Metric Measurements. When making readings on a scale of centimeters and millimeters, first read the number of whole centimeters, then the number of whole millimeters, calling these tenths of a centimeter, and finally estimate the tenths of a millimeter, calling these hundredths of a centimeter. Express this fraction *always as a decimal.*

(2) Measure four other diameters of the same disk in the same way as directed in (1) and find the average of the five measurements. (See Model Tabulation.)

(3) Make a sharply defined mark at the edge of the disk, if, indeed, one has not already been made. Stand the disk edgewise on the rule and bring this mark in coincidence with some centimeter mark on it. Roll the disk edgewise straight along the scale until the mark again comes in contact with the rule. Count up the centimeters and millimeters rolled over and estimate the tenths of a millimeter.

(4) Measure the circumference four more times as in (3), using different parts of the scale.

MODEL TABULATION

	Diameter	Circumference		
	15.35 cm.	48.25 cm.		
	15.36	48.29		
	15.34	48.25	$\frac{\text{Circumference}}{\text{Diameter}}$	= 3.149
	15.30	48.27		
	15.32	48.28	Error	= .007
Sum	76.67	241.34		
Average	15.334	48.268	Percentage of error	= .22 %
	15.33	48.27		

Calculations. Since your individual measurements are doubtful in the second decimal place, the average will surely be doubtful in the third decimal place. If the

third decimal is 5 or more, add one to the second decimal; if it is less than 5, simply drop it. Always record one doubtful figure even if this be a zero, for the zero means that you have looked for the tenths of millimeters but have failed to find any. Furthermore, if the result of a measurement is a whole number of centimeters, write down zeros for the tenths and hundredths; their omission implies that readings only to the nearest centimeter have been made and no attention at all paid to the millimeters and their tenths.

```
15.33)48.27(3.1487
      4599    or
      2280  3.149
      1533
       7470
       6132
      13380
      12264
       11160
       10731
         329
```

To compute the ratio of the circumference to the diameter, divide as here shown, underlining all doubtful figures. Find two doubtful figures in the quotient and then round off to one.

The difference between the accepted value of $\pi = 3.14\underline{2}$ and that here obtained is .007. *To find the percentage of difference or error, multiply the difference by* 100 *and divide the product by the accepted value*; for

$$\frac{.007}{3.14\underline{2}} = \frac{x}{100},$$

whence

$$x = \frac{.7}{3.14\underline{2}} = .22\,\%$$

Another rule particularly good for the rapid estimation of the percentage of error is as follows: *Divide the accepted value by 100, and find how many times this quotient goes into the difference between the accepted and found values.* Thus, since pointing off two decimal places is the same as dividing by 100,

$$\frac{3.14\underline{2}}{100} = .03142,$$

and

$$\frac{.007}{.0314\underline{2}} = .22\,\%$$

It is unnecessary to use more than two figures to express the percentage of error, and usually one suffices.

(5) *Optional.* Wind in a close and regular spiral a fine thread a little less than a meter long around a cylindrical object such as a bottle or can. Note the number of complete turns, and, after unwinding, stretch the thread over the meter stick and determine to tenths of a centimeter the length of the thread used in making the turns. Divide this length by the number of turns to get the circumference. Compute the diameter by dividing by the value of π you have found.

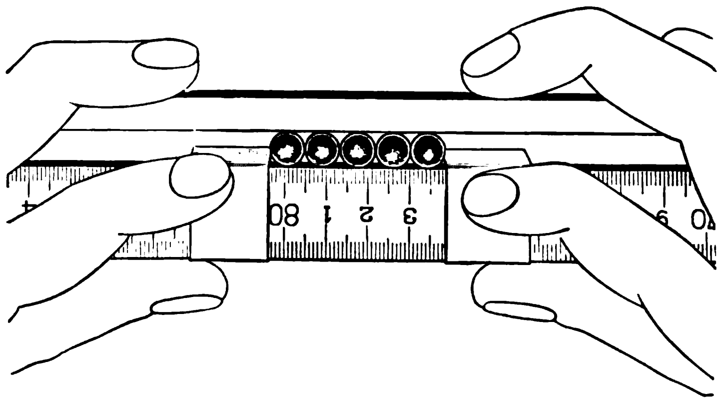
EXPERIMENT II

VOLUME MEASUREMENTS

What to use. Meter stick. Straight edge. Graduated tube. Stiff cards. A dozen or so of bullets (No. 1 buckshot).

I. *To find the volume of a sphere by measuring its diameter.*

What to do. (1) Lay ten bullets in a row alongside the meter stick, pressing them against it with a straight edge or a second rule. Bend the edges of two stiff cards so that they may be used to press the bullets snugly together along the line of their diameters. Measure the length of the row, estimating the tenths of a millimeter. Rolling the bullets over to other positions on the meter stick, make two more such measurements.

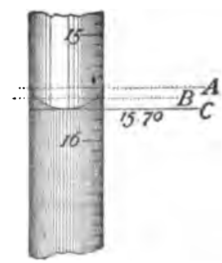


THE BULLETS ARE PRESSED AGAINST ONE ANOTHER BETWEEN THE BENT STRIPS OF CARDBOARD HELD DOWN UPON THE METER STICK BY THE FOREFINGERS, AND ARE KEPT IN LINE BY MEANS OF A STRAIGHT EDGE AGAINST WHICH THE MIDDLE FINGERS PRESS

(2) Divide the average of these lengths by the number of bullets, thus getting the average diameter of a single bullet. Compute the average volume by cubing the diameter and multiplying by $\frac{1}{6}\pi = .52\underline{4}$. (See Model Calculations on page 10.)

II. *To find the volume of a solid by measuring the volume of the liquid which it displaces.*

(3) Fill the graduated tube nearly half full of water, and, holding it vertically, read the position of the surface of the water (*meniscus*), estimating the tenths of the smallest divisions and thus getting the volume to hundredths of a cubic centimeter. With a strip of blotting paper absorb any drops of water that may be clinging to the sides of the tube above the meniscus.



THE PROPER READING IS ALONG LINE *C*

(4) Holding the tube nearly horizontal, roll in the bullets one by one, taking care that no water splashes out and that no more bullets are added than the water can cover. Set the tube again in a vertical position and read the scale opposite the meniscus. The difference in these readings gives the volume of the bullets immersed.

(5) Repeat (4) twice and divide the average of the volumes by the number of the bullets. Compute the per cent of difference between the average volume thus obtained by immersion and that found by diameter measurements.

MODEL TABULATION AND CALCULATIONS

Length of row of 10 bullets	= 9.44 cm.
	9.40
	9.49
Sum	= 28.33
Average	= 9.44
Average diameter of a single bullet	= .944 cm.
Average volume of a bullet = $(.944)^3 \times .524$	= .441 cm.^{3}

Calculations.

.944	.891	.841
.944	.944	.524
3776	3564	3364
3776	3564	1682
8496	8019	4205
.891136	.841104	.440684

	(1)	(2)	(3)
Tube reading after 10 bullets are immersed .... =	14.45 cm.^{3}	18.85 cm.^{3}	16.88 cm.^{3}
Tube reading before 10 bullets are immersed .... =	10.00	14.28	12.37
Volume of 10 bullets .... =	4.45	4.57	4.51

Average volume of a bullet found by immersion .... = .451 cm.^{3}

Per cent of difference* between the results.................. = $\dfrac{.451 - .441}{.451} \times 100 = 2.2\%$

* When the per cent of difference is calculated between two values neither of which may be considered to be "accepted," it is customary to make the larger value play the part of the accepted value.

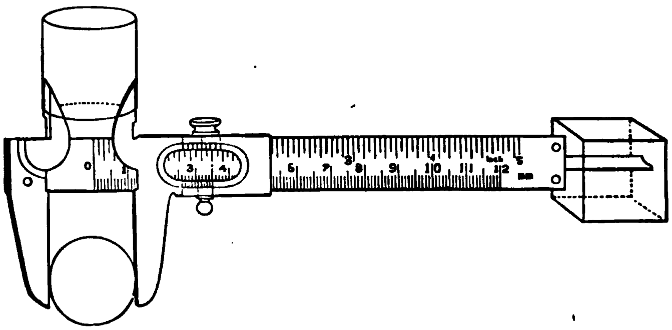
EXPERIMENT III

THE VERNIER

What to use. Meter stick. Graduated tube. The bullets of Experiment II. Cylinder of vulcanite or aluminum. Vernier calipers.

Calipers are instruments for measuring the dimensions of objects which cannot be applied directly to a linear scale. Thus, to measure the diameter of a sphere, some device such as that employed in Experiment II must be used, that has movable parts which can be so adjusted that the distance between them is equal to the diameter. Some forms of calipers merely serve to transfer the length to be measured over to a linear scale, while others are themselves furnished with scales.

Vernier Calipers. The vernier scale is a device invented by Pierre Vernier for measuring fractional parts of a scale division. It consists of an auxiliary scale sliding along a main scale. When the jaws are in contact, the zero of the vernier scale (the *first* line) coincides with the zero of the fixed scale. The vernier scale is 9 mm. long and is divided into 10 equal parts. If, for example, vernier line 4 coincides with some, say the 7th, millimeter mark on the main scale, the vernier line 3 falls .1 mm. short of millimeter mark 6, vernier line 2 falls .2 mm. short of millimeter mark 5, and so on until the zero of the vernier falls .4 mm. short of millimeter mark 3.

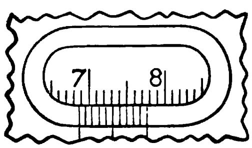


THE LOWER JAWS ARE FOR MEASURING THE OUTSIDE, AND THE UPPER JAWS FOR MEASURING THE INSIDE OF AN OBJECT. THE SLENDER ROD AT THE RIGHT ENABLES ONE TO MEASURE THE DEPTH OF SOME SUCH OBJECT AS A BOX

Set the vernier with its zero in line with 10 mm. on the main scale; the jaws of the caliper are now 10.0 mm. apart. Slide the vernier scale on until its first division (the *second* mark or line) coincides with the 11 mm. line; the sliding scale has been moved .1 mm. and the jaws are 10.1 mm. apart. Adjust the scales so as to bring the second vernier division in line with the 12 mm. mark; the jaws are now separated by a distance of 10.2 mm. In like fashion, by bringing the 3d, 4th, 5th, and so on, vernier divisions in line with the 13th, 14th, 15th, and so on, millimeter marks, we add each time .1 mm. to the distance spanned by the jaws.

To read the vernier, note the left-hand division on the fixed scale nearest the vernier zero, say 68, and the vernier division, say 7, which lies in the same straight line with some fixed scale division (in this case it is 75). The reading is then 68.7 mm. or 6.87 cm.

Many vernier calipers are provided with two sets of jaws, one for measuring exterior and the other for measuring interior dimensions.



THE VERNIER READING IS 6.87 CM.

I. *To find the volume of a cylinder by measuring its dimensions with vernier calipers.*

What to do. (1) With vernier calipers measure the diameters of each of any five of the bullets. Compare their diameters with those found by the method used in Experiment II.

(2) Make five measurements each of the length and diameter of the cylinder. Square the average diameter, multiply by $\frac{1}{4}\pi$ (= .785), and then by the average length to find the volume.

II. *To find the inside diameter of a tube where inside calipers cannot be applied directly.*

(3) Measure the outside diameter of the graduated tube with the vernier calipers in five places at about every 4 cm.³ mark.

(4) With a metric rule measure to tenths of a centimeter the distance between the 1.0 cm.³ and the 20.0 cm.³ marks, thus obtaining the length of a cylinder the volume of which is 19.0 cm.³

(5) Divide the volume of the inside of the tube from the 1.0 cm.³ mark to the 20.0 cm.³ mark, that is, 19.0 cm.³ by the length of this cylinder; the quotient is the average cross-sectional area of the tube in square centimeters. Divide this area by $\frac{1}{4}\pi$ (= .785) and extract the square root of the quotient; the result is the average inside diameter of the tube. Compute the average thickness of the glass from your measurements of the outside and inside diameters of the tube.

(6) *Optional.* If the vernier caliper is made with jaws for interior measurements, find the inside diameter of a tube, tumbler or other appropriate object.

MODEL TABULATION AND CALCULATIONS

Diameter of cylinder .... =	2.52 cm.	Length of cylinder .... =	4.75 cm.
	2.53		4.76
	2.50		4.77
	2.49		4.74
	2.52		4.73
Sum .... =	12.56	Sum .... =	23.75
Average .... =	2.512	Average .... =	4.75
	2.51		

Volume of cylinder .... = $(2.51)^2 \times .785 \times 4.75 = 23.5$ cm.³

Calculations.

2.51	6.30	4.95
2.51	.785	4.75
251	3150	2475
1255	5040	3465
502	4410	1980
6.3001	4.94550	23.5125

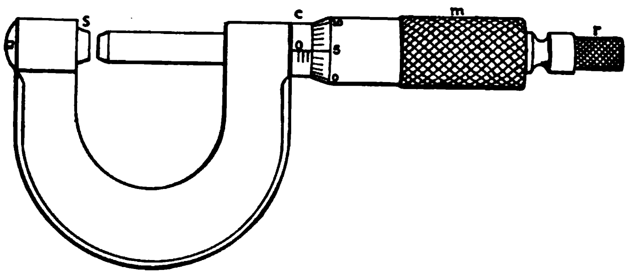
EXPERIMENT IV

THE MICROMETER SCREW

What to use. Micrometer calipers. Steel ball.

The Screw as a Measuring Instrument. When a screw makes a complete turn in its nut, it has moved a distance with respect to the nut equal to that between its consecutive threads; this distance is called the *pitch* of the screw. As the pitch of screws may be made small and as it is not a difficult matter to measure small fractions of a turn, the screw is advantageously applied in certain instruments for measuring small distances; hence the name of *micrometer* (literally *small measurer*).

Micrometer Calipers. The pitch of the screw is .5 mm. The graduations on *c* are in millimeters and give twice the number of whole turns of the screw. The circular scale is divided into 50 equal parts, their length not being in the metric system but depending solely upon the size of the instrument. A fiftieth of a turn (measured on the circular scale) corresponds then to a forward or backward movement of the screw amounting to $\frac{1}{50}$ of .5 mm. or $\frac{1}{100}$ of a millimeter. By estimating the tenths of a circular division, measurements may be made to thousandths of a millimeter.



THE READING IS .3050 CM.

To use the instrument, turn the screw at the milled head *m* until the jaws come together, and note the pressure needed to bring the zero of the circular scale in line with the zero of the straight scale. If more than a gentle pressure has to be applied, have the instructor adjust the stop *s*. Practice closing the jaws until you have trained your muscles to bring the zero lines to coincidence even when you are not looking. Afterwards, in measuring an object, always exert the same force you have found necessary to bring the jaws together properly.

Some instruments are provided with a "ratchet stop" *r* which clicks when the jaws are pressed together or against an object. If the "ratchet stop" does not click when it is turned until the jaws are closed together with the two zeros in coincidence, the instrument needs adjustment.

To find the volume of a sphere by measuring its diameter with micrometer calipers.

What to do. (1) Hold the ball between the jaws of the caliper and turn the screw until they close upon it with the proper pressure. In reading, be sure to note whether the screw has made more than one turn since the zero of the graduated circle has left the last millimeter mark to the left, as, if it has, .05 cm. are to be added to the reading. Estimate the tenths of the circular scale divisions. Make five measurements.

(2) Compute the volume of the sphere, bearing in mind that as many figures should be retained in the value of $\frac{1}{6}\pi$ as are obtained in the measurements. (See Model Calculations.)

(3) *Optional.* Measure the thickness of any articles your instructor may direct, such as that of wires, of a hair, of a leaf of this book, and so on.

MODEL TABULATION AND CALCULATIONS

```
Diameter of steel ball ............................ = 1.2721 cm.
                                                      1.2725
                                                      1.2726
                                                      1.2724
                                                      1.2722
                                                      ------
                                      Sum ........ = 6.3618
                                      Average..... = 1.27236
                                                      1.2724
```

Volume of ball $= (1.272\underline{4})^3 \times .5235\underline{9} = 1.078\underline{6}$ cm.^{3}

Calculations.

```
      1.2724            1.2724           .52359 *
      1.2724             1.619             2.06
  ----------       ---------        ---------
       50896          114516           314154
      25448           12724           104718
     89068           76344           ---------
    25448           12724            1.0785954
   12724           ---------
  ----------       2.0600156
  1.61900176
```

* The multiplication as here carried out with the omission of the two ciphers in the number 2.0600 gives six significant figures, while only five were obtained in the measurements. By retaining the ciphers and multiplying, but five significant figures are obtained. While the omission of ciphers may give (as in the second multiplication above) the right number of significant figures, yet such is often not the case. See the rules on page 15.

```
     2.0600
     .52359
    -------
     185400
    103000
    61800
   41200
  103000
 -----------
 1.078595400
```

SIGNIFICANCE OF FIGURES

A study of the model computations of the foregoing experiments shows that the number of sure figures obtained after a multiplication or division of numbers containing doubtful figures is the same as the least number of sure figures occurring in any factor. Thus, in Experiment I, measurements were made expressible by three sure and one doubtful figure, or *four significant figures,* and their quotient likewise contained three sure and one doubtful figure. But in Experiments II and III only three significant figures were obtained. In Experiment IV, however, the fifth figure only was doubtful so that the diameter of the ball was expressed by five significant figures. The value of $\frac{1}{6}\pi$ was therefore also given with five figures.

The position of the decimal point has nothing whatsoever to do with the significance of figures. Thus the diameter of the ball was found to be 12.724 mm. or 1.2724 cm. — three decimal places with the millimeter as unit and four with the centimeter as unit; but the number of significant figures is the same in both cases. No more do ciphers or zeros used to locate the position of the decimal point have any influence on the number of significant figures. Thus the diameter of the ball is .012724 *meters.* In such a number as .0906, the cipher following the decimal point is not significant, but the cipher between the 9 and the 6 is significant. The cipher in the number $6.3\underline{0}$ was retained only for the purpose of showing the number of significant figures. (See the second multiplication in Experiment III; also the footnote on page 14.) The distance between the sun and the earth is $9\underline{3}{,}000{,}000$ miles; the 9 is a sure figure and the 3 is doubtful, the six ciphers serving merely to locate the decimal point.

The following statements regarding significant figures should be memorized:

I. *Ciphers annexed or prefixed to a number merely to locate the decimal point are not significant.*

II. *Ciphers that have nothing to do with the location of the decimal point are significant.*

III. *Keep only one doubtful figure in a number, substituting ciphers for the rejected figures, if needed to locate the decimal point.*

IV. *Increase the first doubtful figure by* 1, *if the rejected second figure is* 5 *or more.*

V. *In products, keep no more figures than occur in the factor having the smallest number of significant figures, except in case the doubtful figure is very nearly sure (as determined by inspection of the data), when two doubtful figures may be retained in the calculations until the final product is obtained, which must contain only one doubtful figure.*

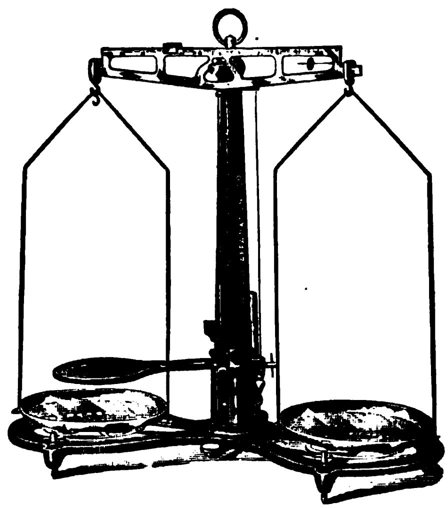
VI. *In quotients, keep only as many figures as are found in the number (dividend or divisor) having the fewest significant figures. Find two doubtful figures and apply Rules III and IV.*

EXPERIMENT V

MASS MEASUREMENTS

What to use. Beam balance. Weights. Graduated tube. Solids the volumes of which were found in the foregoing experiments. Thermometer.

The Beam Balance. This consists of a light stiff beam balanced at its center on a knife edge resting upon a smooth plate at the top of a supporting column or pillar. Near the ends of the beam and equally distant from the central knife edge are two other knife edges facing upwards to which the bows holding the pans are hung. A pointer attached to the beam swings before a scale fixed at the base of the pillar, and serves to magnify the movements of the beam. With an accurately made instrument in perfect adjustment, when equal masses are placed in the pans, the pointer will vibrate over an equal number of divisions on each side of its position of equilibrium, which is at the middle of the scale. At the end of one or both arms of the balance are small nuts which may be screwed in or out so as to make the pointer come to rest at the center of the scale. A handle in front of the base operates an arrestment by means of which the undue swinging of the pans can be stopped. By means of leveling screws the pillar is made to stand vertically, as shown by the plumb line alongside the pillar.



PERFECTED BEAM BALANCE

In some forms of balance the use of small weights is done away with, the beam bearing a scale for part or all of its length along which a weight slides. The position of the sliding weight gives the amount of the smaller weights, usually 10 or 5 grams, and their subdivisions. The directions here given have reference to a balance with detached weights down to centigrams, but may be readily applied to balances with graduated beams.

Mass and Weight. The mass of a body is measured by comparing the pull of the earth upon it with the pull that the earth exerts upon certain standard masses. In an accurately constructed and properly adjusted balance, the masses placed in the two pans are equal to each other when the balance is in equilibrium. The earth-pull upon a body is called its *weight*, and the standard masses are known as *weights*. Although mass and weight are distinct things, the number expressing the value of the same amount of each is the same.

I. *To find the mass of a body by the method of equal swings.*

What to do. (1) Level the balance, if the pillar is not vertical. Brush any dust off the pans and gently release the beam. If the pointer does not start to vibrating, carefully waft with the hand a current of air down upon one of the pans, avoiding, however, making the pans swing on their bearings. If the pointer does not pass over the same number of divisions on each side of the center of the scale, arrest the beam just as the pointer is passing its central position, and thus stop the vibrating without appreciable jarring. If the pointer went further to the right, say, than to the left, screw out a turn or so the nut at the end of the right arm or screw in the left-hand nut. Again release the beam and see if the excursions of the pointer on both sides of the middle of the scale are within a scale division of being the same, allowance being made for the fact that friction makes each succeeding excursion less. Continue in this way until the excursions are within less than a division of being the same on both sides.

(2) Place the object in the middle of the left-hand pan, and in the right-hand pan a weight which you think may have a mass equal to that of the object. Release the beam and note in which direction the pointer tends to move. If it moves to the left, the weight is too large, and must be removed and a smaller one substituted. If it moves to the right, the weight is not heavy enough and the next smaller one should be added. Add each smaller weight in succession, skipping none, removing it if found too heavy, and leaving it if too light.

(3) When such weights are placed in the pan as cause the pointer to vibrate within a scale division or so of the center of the scale, their sum may be taken as the mass of the object. Count up the weights on the pan and, before removing them, count also the empty pockets in the block or box from which the weights were taken. These two counts check each other and lessen the chances of mistake. Record the weight with the gram as the unit. Thus, if the 20, 10, 5, 2, .5, .2, and .01 gram-weights were upon the pan the weight of the object would be 37.71 g.

(4) Find the mass of the other objects in the same fashion.

Density. By density is meant the mass of the unit volume of a substance, as the number of grams in a cubic centimeter, the number of pounds in a cubic foot, and so on. A density determination involves, then, the determination of mass and of volume.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

II. *To find the density of the objects the volume and mass of which have been determined.*

(5) Compute the density of each solid measured and weighed by dividing its mass (in grams) by its volume (in cubic centimeters). Weigh ten bullets (Experiment II) and take the average weight. Find the per cent of error between your values and the accepted values.

MODEL TABULATION

Mass of steel ball	= 8.45 g.
Volume of steel ball	= 1.0786 $cm.^3$
Density of steel ball	= 7.83
Accepted value for the density of steel	= 7.85
Per cent of error	= .38%

(Use a similar form for each of the other substances.)

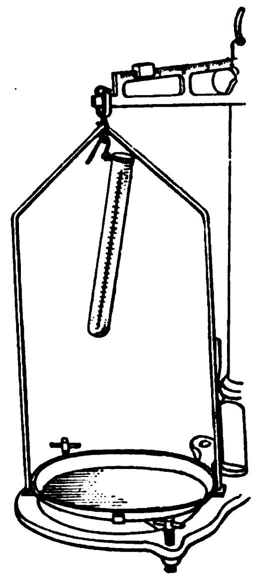
III. *To calibrate a graduated tube.*

Calibration. Calibration literally means to find the caliber or bore of a tube. In physics the word is used to denote the determination of the errors in the graduations of an instrument or the comparison of its graduations with those of a standard instrument. A tube is graduated, say, in cubic centimeters, but the accuracy of the graduations depends upon the skill and care of the manufacturer, so that while a reading may indicate that the volume is 20.0 cm., in reality the volume may be somewhat greater or smaller than that read. The complete calibration of an instrument is usually a tedious operation, for it involves the determination of the possible errors for a large number of its graduations.

Density of Water. One cubic centimeter of water has a mass of one gram only at 4° Centigrade or 39° Fahrenheit. At this temperature the density of water is one; its density at some other common temperatures on the Centigrade scale are as follows:

Temperature	0°	10°	15°	16°	17°	18°	19°	20°
Density	.9999	.9997	.9991	.9990	.9989	.9986	.9984	.9982
Temperature	21°	22°	23°	24°	25°	26°	27°	28°
Density	.9980	.9978	.9976	.9973	.9971	.9968	.9960	.9958

(6) Wipe the graduated tube dry, inside and outside, and hang it by a wire or cord from the hook of the balance. Find its mass to hundredths of a gram.



(7) Fill it full to the extent of its graduation with water and weigh again. Note the temperature of the water. The difference between the two masses is the mass of the volume of water held by the tube. Multiply this volume by the density of the water at the temperature it has when the volume reading is made. This gives the accepted value of the mass of water contained in the tube. Compute the per cent of difference between this accepted value and the value you have found.

(8) *Optional.* Calibrate the tube when it is about (*a*) a third; (*b*) a half full of water.

MODEL TABULATION

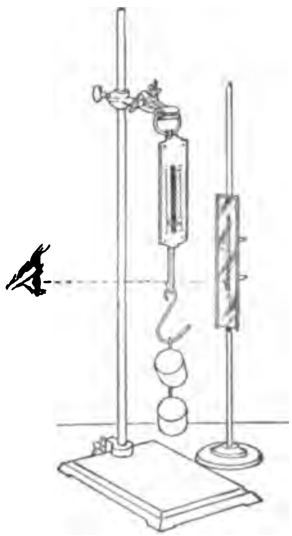
Weight of tube and 20.0 cm.³ of water at 21°	= 57.17 g.
" " "	= 37.25
" " 20.0 cm³ of water at 21°	= 19.92
Accepted value for the mass of 20.0 cm.³ of water at 21°	= 19.96
Difference between accepted and found values (error in graduation)	= .04
Per cent of difference	= .2%

EXPERIMENT VI

FORCE MEASUREMENTS — (HOOKE'S LAW)

What to use. 2000-g. spring balance. Stand with burette clamp. Weights making up combinations of 400, 800, 1200, 1600 and 2000 g. Vernier calipers or metric rule. (Use dividers with the rule, if available). A mirror scale can be used to advantage instead of the calipers or rule. If a Jolly balance is available it may be substituted for the spring balance.

IMPROVED SPIRAL SPRING BALANCE



ONE FORM OF IMPROVISED JOLLY BALANCE

Jolly Balances. Besides in the familiar spring scale or dynamometer, spiral springs in specialized forms are used in laboratories for making quite delicate measurements. Of the two forms in general use, one was invented by Jolly in 1867 and is therefore frequently called a "Jolly Balance," while the other was invented in 1900 by the author. Both forms are used in essentially the same way as the common spring balance. As their scales are in centimeters and decimal fractions thereof, it is necessary to ascertain for each instrument the particular relation between the elongations of its springs and the weights producing them. If 5 g., for instance, stretch the spring 25 cm., then, by Hooke's law, 1 g. will stretch it $\frac{25}{5}$ or 5 cm., and an elongation of 1 cm. will correspond to a weight of $\frac{5}{25}$ or .2 g.

A Jolly balance may be improvised as follows: Support a spiral spring from a stand so that it hangs in front of a metric rule or mirror scale. A pointer made of a strip of tin or cardboard is fastened to the lower end of the spring, which is bent into a hook for attaching weights or for supporting a pan made of a metal box cover hung on three fine cords or wires.

To determine the relationship between stress and strain in the case of a spiral spring; to compare forces by means of measurements on the changes their application produces in the dimensions of a body; to calibrate a spiral spring balance.

What to do. (1) Hang the ring of a spring balance from the clamp of the stand. If the pointer or index does not point precisely to the zero of the scale, estimate to fifths of a division its position on the scale.*

(2) Suspend 400 g. from the hook and read the position of the index to fifths of a scale division, after having jostled the balance a little so as to prevent errors arising from the index or spring sticking to the case. Before passing to (3), hang on the hook in succession 800 g., 1200 g., 1600 g., and 2000 g. and note the readings.

Elongations Measured by a Mirror Scale. If a mirror scale is available, adjust its height on the support until the eye can see the horizontal upper surface of the projecting part of the drawbar just in line with its image in the mirror, the line of sight grazing the zero of the scale. Each time a weight is suspended, read to hundredths of a centimeter the position on the scale where the line of sight crosses it when the eye is so placed as to make the drawbar just cover its image.

(3) Measure to hundredths of a centimeter with a vernier caliper or a metric rule (using dividers, if available) the distances between the positions of the pointer when no weight was hung from the balance and when each of the weights directed was suspended therefrom. These distances are the elongations of the spring.

(4) If the differences between the weights and the scale readings are in any case more than 25 g., it is recommended that other weights differing by only 100 g. be used also, so as to more closely find the errors of the balance. When the balance is used in subsequent work, apply the corrections as determined by this calibration of the spring.

(5) How do the corresponding weights and elongations compare? Allowing for experimental errors, does doubling, trebling, etc., the weight produce double, treble, etc., the elongation? If so, the two quantities — weight and elongation, *i.e.*, stress and strain, are directly proportional. When two variable quantities vary directly, the quotients of the values of one by the corresponding values of the other are equal. Divide the elongations by the weights, and see if such is the case. State the relationship between stress and strain in the case of a spiral spring.

MODEL TABULATION

Weights (stresses) A	Scale Readings B	Balance Corrections A − B	Elongations (strains) C	$\frac{C}{A}$
0 g.	25 g.	− 25 g.		
400	425	− 25	1.25 cm.	313 × 10^{-5}†
800	825	− 25	2.42	303
1200	1200	0	3.63	303
1600	1590	+ 10	4.85	303
2000	2025	− 25	5.95	298
				Average . . 301

† The 10^{-5} means that the number to which it is affixed is a decimal of five places — 304 × 10^{-5} = .00304.

* The linear scale on the balance is graduated in equal divisions each of which corresponds to 25 g. These divisions are so close together that estimations of fifths only are advisable, the smallest weight (estimated) then being 5 g.

In the last column of the Model Tabulation for the Experiment on Force Measurements it is seen that the quotients are, if due allowance be made for unavoidable errors, the same. This means that the weights and the elongations vary in the same way; they vary directly or are directly proportional.

Another method of finding out in what relation two sets of quantities stand consists in plotting them on cross-section paper and constructing a line or *graph* therefrom. Cross-section paper (also called squared or coördinate paper) is ruled in squares, the lines commonly being two millimeters apart and every fifth line (centimeter) being ruled heavier than the others. The lower left-hand corner is usually made the *origin O*. The horizontal line through the origin is called the *axis of abscissas* or *axis of X*, and lengths laid off on it are *abscissas*. The vertical line passing through the origin is called the *axis of ordinates* or *axis of Y*, and lengths measured off on it are *ordinates*. (See page 24.)

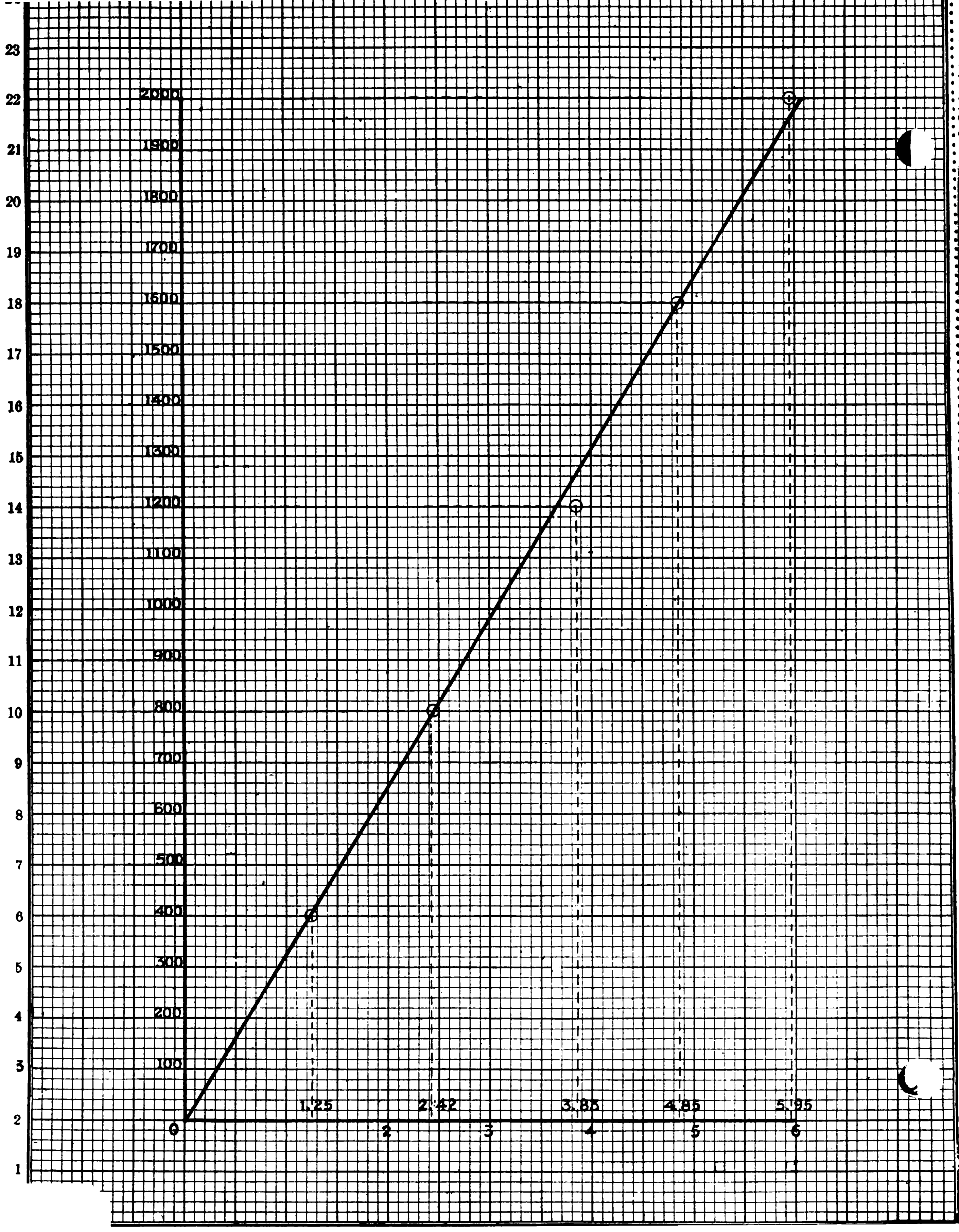
Referring to the Model Tabulation (page 22) we see that the maximum weight is 2000 g. and the maximum elongation is 5.95 cm. Our cross-section paper has a width of 18 cm., so that by adopting a scale of 3 cm. of paper to represent 1 cm. of elongation, the elongations when laid off on the axis of abscissas would occupy the full width of the paper. Such a scale, however, is not as convenient to use as a scale where 2 cm. of paper stand for 1 cm. of elongation. Never use a scale so small that only a little of the sheet of paper is occupied, nor so large that there is not room enough for the completed work.

A scale of 1 cm. of paper to represent 100 g. of weight laid off on the axis of ordinates will probably be best. In order to have more room at the margins, the origin is moved to the position shown in the figure.

It is apparent that, when no weight is hung from the spring, there is no elongation. Hence the starting point of the graph is at the origin. The elongation for 400 g. is 1.25 cm. We make a cross or a dotted circle 4 cm. from the axis of abscissas and 2.5 cm. from the axis of ordinates. The other points of the graph are located in a similar way. If these points were connected by straight lines, we would see that they formed a slightly broken line. As the graph is the result of experimental work which is subject to error, we try to draw a straight line through as many points as possible and in such a manner that such points as do not come on the line are distributed symmetrically on either side of it. Thus, in the illustration, the first, second and fourth points fall on the line, while the third point is about as far from it on one side as the fifth point is on the other side. *When a graph is a straight line, the two sets of quantities are directly proportional.*

If, in plotting the data of an experiment, one of the points falls considerably out of the graph along or near which the other points lie, it is likely that a mistake has been made in obtaining the data. A graph is therefore useful in detecting errors of experimentation or calculation.

A graph may be used to find the values for one of the quantities corresponding to certain values of the other quantity. Thus, suppose that it is required to find the weight that will stretch the spring 4.00 cm. The graph is seen to cross the axis of ordinates very near to a point corresponding to 1300 g. when the value of the abscissa is 8, corresponding to an elongation of 4 cm. Hence 1300 g. will stretch the spring 4 cm.

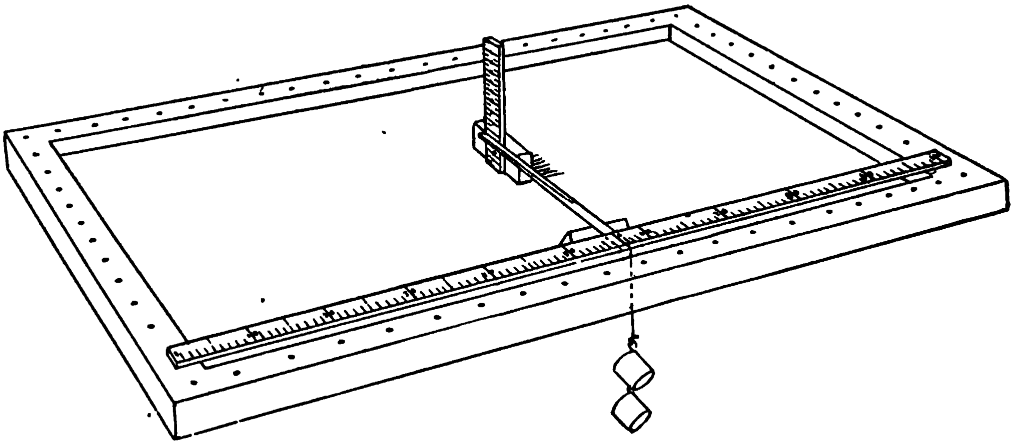


23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1.25
2.42
3.83
4.85
5.95
2
3
4
5
6

EXPERIMENT VII

ELASTICITY OF BENDING

What to use. General utility board.* Meter stick. Lever multiplying device,† consisting of a wooden triangular prism, a light stick or indicator a little over 30 cm. long and a 20 cm. metric rule mounted vertically on a base. Several 100 and 200 g. weights. Stout cord.



GENERAL UTILITY BOARD WITH ACCESSORIES FOR DETERMINING THE LAWS OF BENDING

To ascertain the relation between bending force and bending strain.

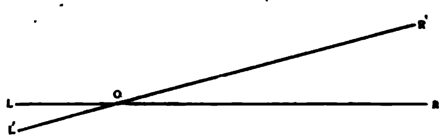
What to do. (1) Tie a cord around the meter stick at about the middle and lay the stick across the narrow ends of the general utility board so that the cord hangs down through the hole bored in the panel.

(2) Set the prism on the general utility board with its upper edge 2.5 cm. from the edge of the meter stick Place the indicator on the prism's edge with one end projecting under the meter stick. Adjust the apparatus by propping up the prism, or by bending the meter stick slightly by hanging a 100 or a 200 g. weight to the cord, until the lever

* The general utility board consists of a stout wooden frame about 60 × 100 cm. in which is fitted a panel of thin wood. Holes are bored through the frame, in which pegs may be inserted for the attachment of various pieces of apparatus. With a few simple accessories the general utility board can be used to advantage in a number of experiments, whence its name.

A substitute for the general utility board can be made as follows: Strips of wood about $1\frac{1}{2}'' \times 2''$ are cut of such lengths as to reach across a table top. Holes in which 20-penny nails fit snugly are bored through the strips 5 cm. apart. Two such strips clamped about a meter apart across the table top are nearly as convenient as the general utility board itself.

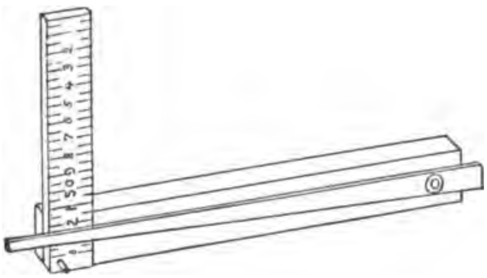
† **The Lever as a Multiplying Device.** Let LOR represent a light rigid bar capable of rotating about an axis O. Such an arrangement is called a lever and LO and RO are its arms. If the fulcrum (as the axis of rotation is called) be fixed, the short arm of the lever slipped under a rod, and a linear scale set vertically alongside the long arm, when the rod is depressed, it will slip a little on the lever. If the distance from the outer edge of the upright scale is, say, ten times the distance from the fulcrum to the inner edge of the rod, the rise of the end of the lever alongside the scale is ten times greater than the depression of the rod. The proof is as follows: Suppose lines to connect L to L' and R to R'. Then, as the triangles $L'LO$ and $R'RO$ would be similar,



$$\frac{L'L}{R'R} = \frac{LO}{RO} = \frac{1}{10}$$

is about horizontal. Then set the upright metric rule so that its outer edge is 25 cm. from the prism's edge. What is the ratio of the lengths of the arms of the lever? Be careful to preserve these relative distances unaltered during the experiment.

(3) Read to hundredths of a centimeter the position of the indicator on the outer edge of the vertical scale. Carefully avoiding any jar that might disturb the adjustment, hang a 100 g. weight to the cord, and read the scale. If after removing the weight the lever does not come back in to its original position, the adjustment has been disarranged, and this determination must be rejected. Hang in succession 100 g., 200 g., 300 g., 400 g., etc., to the cord until the end of the long arm of the lever has risen at least 15 cm. and measure the positions on the scale. No determination is to be considered trustworthy unless the unloaded meter stick comes back to its original position.



CONVENIENT FORM OF LEVER MULTIPLYING DEVICE

(4) Subtract the first scale reading from each of the other ones, and divide the remainder by ten; the quotient, since the ratio of the lever's arms is 10 : 1, will be the deflections of the stick. Divide these deflections by the forces producing them. How do the quotients compare? In what relationship does bending stand to bending force? Construct a graph with the weights as ordinates and the deflections as abscissas.

TABULATION

WEIGHTS (STRESSES) A	SCALE READINGS B	DEFLECTIONS (STRAINS) C	$\frac{C}{A}$
0 g.	cm.	cm.	
100 g.	cm.	cm.	
etc.	etc.	etc.	

EXPERIMENT VIII

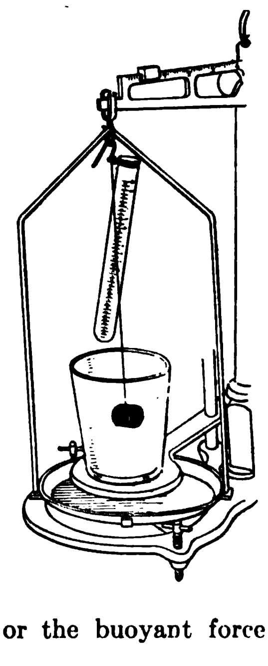
ARCHIMEDES' PRINCIPLE

Sunken and Floating Bodies. When a solid is placed in a liquid that has no solvent action upon it, a volume of the liquid is displaced which is equal to the volume of the solid, or, in case the solid floats, equal to the volume of the solid below the surface of the liquid. This displacement causes a rise in level of the liquid, and the raised liquid exerts a pressure upon the solid. If the solid sinks, only a portion of its weight is employed in raising the displaced liquid; if it floats, however, all of its weight is so employed, and the floating body loses all of its weight. That is to say, if a solid attached by a cord to one arm of a beam balance or a spiral spring balance is suspended in water, it appears to lose all of its weight, if it floats, and part of its weight, if it sinks. The pressure of the elevated mass of liquid has the effect, because of the transmission of the pressure in all directions, of buoying up the solid displacing the liquid. If, on the other hand, a solid attached to a cord held in the hand or by a stand is suspended in a liquid contained in a vessel set on a balance pan, an increase of weight is observed; the water seems to gain in weight. The liquid displaced by the solid is raised, thus increasing the liquid's depth; and since pressure is proportional to depth, an increase in weight is observed. Since one cubic centimeter of water weighs one gram, the number expressing in cubic centimeters the volume of the solid is the same as the number expressing in grams the weight of the water displaced.

What to use. Beam balance with weights to decigrams. Graduated tube. Vulcanite or aluminum cylinder. Pipette* or medicine dropper. Tumbler of water. Fine thread or horsehair. Vernier or micrometer calipers. Stand with clamp holding a stick or rod horizontally.

I. *To find a relationship between the loss in weight of a submerged body and the weight of the liquid displaced by it.*

What to do. (1) Measure the linear dimensions of the vulcanite or aluminum cylinder with the calipers and compute its volume to tenths of a cubic centimeter.



(2) Hang the cylinder from the balance-pan hook by a thread or horsehair so that only a single strand will pass through the water in the tumbler when the cylinder is submerged.

(3) Either substitute the counterpoise for the left-hand pan or set a platform over it, and suspend the dried graduated tube from the hook on the balance-arm.

(4) Weigh the suspended apparatus to decigrams. Bear in mind that the weight of the thread or hair must be so slight as to be negligible in comparison with the weight of the tube and stand. So break off all loose ends. Also remember that the friction between the thread and the water's surface is relatively large. So have only one strand passing from the cylinder to the tube.

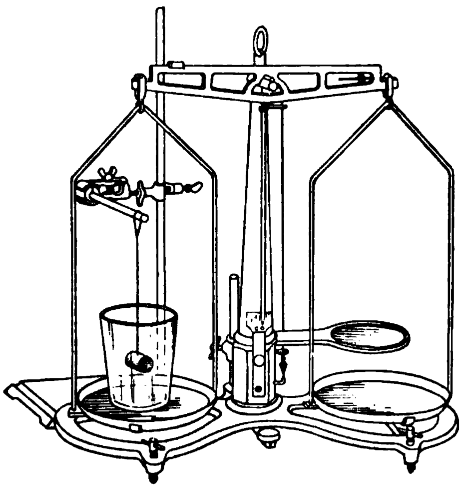
(5) Bring the tumbler about three-fourths full of water under the glass tube so as to rest on the platform or balance base and totally submerge the cylinder. Remove any air bubbles that may appear on the cylinder by lifting it up out of the water for an instant. See to it that the cylinder does not touch the sides of the tumbler, and find the weight. The difference between these two weights is the loss in weight of the solid, or the buoyant force exerted by the liquid.

* A pipette may be made by drawing out in a Bunsen flame one end of a piece of glass tubing into a jet.

(6) Put the weights required in (4) back again on the pan, and by means of the pipette cautiously fill water into the graduated tube until equilibrium is again attained. Remove any excess of water by the aid of narrow strips of blotting paper. Why is the weight of the water added equal to the loss in weight? Read to tenths of a cubic centimeter the volume of the water added.

(7) Without appreciable error 1 cm.^{3} of water may be taken to weigh 1 g. in this experiment. Compare the number representing the loss in weight with that representing the volume of the cylinder (which is also the volume of the water displaced). Also compare the volume of the water displaced with that put into the graduated tube.

II. *To compare the change in weight that a liquid experiences when a solid hung from an outside support is immersed in it, with the weight of the liquid displaced.*



(8) Fill a tumbler a little over three-fourths full of water, wipe the outside of it dry, set it on the balance-pan and weigh it to decigrams.

(9) Hang the cylinder from the arm of the stand by a thread or horsehair of such length that the cylinder can be submerged in the water without interfering with the action of the balance. Find the weights that must be put into the pan to restore equilibrium.

(10) How does the gain in weight or downthrust due to the submersion of the cylinder compare with its loss in weight or upthrust found in (5)? How do the amounts of water displaced, i.e., *raised*, compare in the two cases?

TABULATION

I

Diameter of cylinder ....cm. Length of cylinder ....cm.
Volume of cylinder ....cm.^{3}
Weight of graduated tube and cylinder in air .... g.
" " " " " " with cylinder in water .... g.
Loss in weight .... g.
Weight of water put into graduated tube .... g.
Volume " " " " " " ....cm.^{3}
Weight of water displaced by cylinder .... g.
Difference .... g.
Per cent of difference .... %

II

Weight of tumbler and water with cylinder submerged .... g.
" " " " " .... g.
Gain in weight .... g.
Weight of water displaced .... g.
Difference .... g.
Per cent of difference .... %

EXPERIMENT IX

SPECIFIC GRAVITY OF A LIQUID

Specific Gravity. A body is said to be *heavy* when its weight is great in comparison with its volume, and *light* when its volume is great in comparison with its weight. These rather vague terms are in common use, but to express definite degrees of lightness and heaviness, the term *specific gravity* is employed. The adjective specific indicates that a comparison is to be made between a certain property — weight in the case in hand — of a substance and the same property of another standard substance. The numerical value of the property in question is expressed as a ratio. *Specific gravity is* defined to be *the ratio between the weights of equal volumes of substances, one of which is taken as a standard.* The standard adopted for solids and liquids is water.

What to use. Beam balance and weights to centigrams. Graduated tube. Water and kerosene.

To find the specific gravity of a liquid by comparing the weight of a certain volume of it with the weight of an equal volume of water.

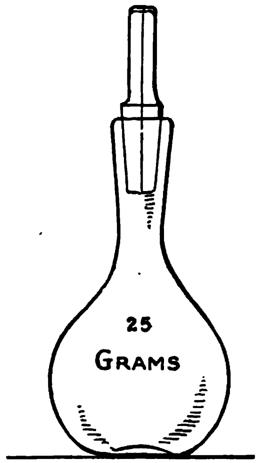
What to do. (1) Dry the graduated tube, hang it from the balance-arm hook, and weigh it to centigrams.

(2) Fill it to the limit of its graduation with water and weigh. (See the lower figure on page 9.)

(3) Empty out the water and dry the tube.

(4) Pour in a volume of kerosene equal to that of the water and weigh again.

(5) Subtract the weight of the tube from each of the other two weights. Divide the weight of the kerosene by the weight of the water. Find the per cent of difference between your value and the accepted value.*



SPECIFIC GRAVITY BOTTLE

TABULATION

Weight of tube filled with water to 20.0 cm.³ mark	g.
" " " empty	g.
" " 20.0 cm.³ of water	g.
Weight of tube filled with kerosene to 20.0 cm.³ mark	g.
" " " empty	g.
" " 20.0 cm.³ of kerosene	g.
Specific gravity of kerosene	
Accepted value for specific gravity of kerosene	
Per cent of error	%

* More accurate determinations of volume may be made if the graduated vessel has a narrow neck. Bottles with ground glass stoppers perforated with a fine hole are made expressly for specific gravity determinations. Any glass-stoppered (especially perfumery) bottles make good specific gravity bottles, if a side channel is filed out of the stopper. The procedure is the same as above. Weigh the bottle filled with water and then with the other liquid, and subtract from each the weight of the empty bottle.

EXPERIMENT X

SPECIFIC GRAVITY OF A HEAVY SOLID

Archimedes' Principle and Specific Gravity. The volume of a submerged body is equal to that of the liquid it displaces; the very fact of submersion guarantees *equality of volumes.* The loss of weight is, by Archimedes' principle, equal to the weight of the liquid displaced. Hence

$$\textit{Specific gravity} = \frac{\textit{Weight in air}}{\textit{Loss of weight in water}}$$

When an insoluble solid is weighed in various liquids, the volumes of the displaced liquids are all equal, and the weights of these equal volumes are equal to the losses of weight in each liquid. Hence

$$\textit{Specific gravity of a liquid} = \frac{\textit{Loss in weight of a solid in the liquid}}{\textit{Loss in weight of the same solid in water}}$$

Spiral Spring Balance in Specific Gravity Work. Jolly balances may be used instead of beam balances in determining specific gravities. As the elongations are proportional to the weights producing them, and as specific gravity is a ratio, the elongations may be used directly in the calculations, it being unnecessary to reduce them to the corresponding weights.

$$\textit{Specific gravity (of solid)} = \frac{\textit{Elongation in air}}{\textit{Elongation in air} - \textit{Elongation in water}}$$

$$\textit{Specific gravity (of liquid)} = \frac{\textit{Elongation in air} - \textit{Elongation in liquid}}{\textit{Elongation in air} - \textit{Elongation in water}}$$

What to use. Beam balance with weights to centigrams (or Jolly balance). Solids as directed by the instructor. Tumbler of water. Fine thread or horsehair.

To determine the specific gravity of an insoluble solid sinking in water.

What to do. (1) Hang the solid by a thread or horsehair (See Experiment VIII) from the arm of the balance and weigh it (*a*) in air; (*b*) in water.

(2) Compute its specific gravity and find the per cent of difference between your value and the accepted value.

If a Jolly balance is used, hang the solid from the spring and find the elongation it occasions in air, and in water. From these data calculate its specific gravity.

TABULATION

Weight of solid in air	g.
" " " " water	g.
Loss in weight	g.
Specific gravity	
Accepted value for specific gravity	
Per cent of error	%

EXPERIMENT XI

SPECIFIC GRAVITY OF A LIQUID BY THE IMMERSION METHOD

Read the preliminary notes of Experiment X.

What to use. Beam balance with weights to decigrams (or a Jolly balance). Sinker (the vulcanite cylinder will answer, but a glass rod with a hook for attaching the thread is better, as it may be lowered within bottles). Bottles or tumblers containing water and the liquids to be tested.

To find the specific gravity of a liquid by weighing a solid in it and in water.

What to do.

WITH BEAM BALANCE

(1) Weigh the sinker in (1) air, (2) water, (3) the liquid.

WITH JOLLY BALANCE

(1*a*) Find the elongation of the sinker in (1) air, (2) water, (3) the liquid.

WITH BOTH BALANCES

(2) Divide the loss of weight in the liquid (or the difference of the elongations) by the loss of weight in water (or the difference of the elongations). The quotient is the specific gravity of the liquid. Find the per cent of difference between your value and the accepted value.

TABULATION

WITH BEAM BALANCE

Weight of sinker in air	g.
" " " " water	g.
" " " " the liquid	g.
Loss of weight in water	g.
" " " " the liquid	g.

WITH JOLLY BALANCE

Elongation produced by sinker in air	cm.
" " " " " water	cm.
" " " " " kerosene	cm.
" corresponding to loss of weight in water	cm.
" " " " " " " kerosene	cm.

Specific gravity found	
" " accepted	
Per cent of error	%

EXPERIMENT XII

SPECIFIC GRAVITY OF A LIGHT SOLID

Read the preliminary notes of Experiment X.

What to use. Beam balance with weights to centigrams (or a Jolly balance). Cork or a piece of paraffin or wax. Lead strip (or cylinder with a hook) heavy enough to sink the cork or other light solid. Fine thread or horsehair. Tumbler of water.

To determine the specific gravity of a solid that floats on water.

What to do. (1) Weigh the cork in air.

(2) Weigh the lead sinker suspended in water.

(3) Attach the sinker to the cork and weigh both under water.

(4) The cork not only loses all of its weight when submerged but also makes the lead lose some of its weight. The weight of the cork under water is found by subtracting the weight of the sinker in water from the weight of both sinker and cork in water. Why does this yield a negative value? Subtract the weight of the cork in water from its weight in air (remembering that subtracting a negative quantity gives the same result as adding an equal positive one), and thus obtain the weight of the water equal in volume to the volume of the cork. Divide the weight in air by this last weight; the quotient is the specific gravity sought.

(5) With a Jolly balance the procedure is the same, elongations being substituted for weights.

TABULATION

Weight of cork in air	g.
" " sinker in water	g.
" " cork and sinker in water	g.
" " equal volume of water	g.
Specific gravity found	
" " accepted	
Per cent of error	%

EXPERIMENT XIII

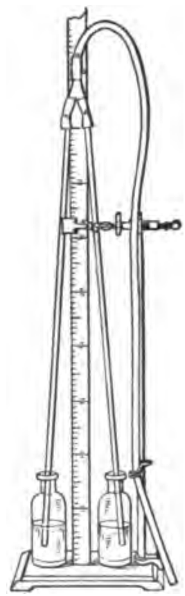
SPECIFIC GRAVITY OF A LIQUID BY HARE'S METHOD

Specific Gravity from Volume Measurements. Suppose that a certain substance is twice as heavy as water; its specific gravity is expressible by the number 2, and one gram of it has a volume of .5 cm.^{3} Now if we did not know the specific gravity of this substance but did know that .5 cm.^{3} of it weigh one gram, then, since one cubic centimeter of water weighs one gram, it follows that this substance is twice as heavy as water; for when equal weights of water and the substance are compared as to volume, the volume of the water is double that of the substance in question. In general, then, the specific gravity of a substance may be found by measuring the volumes of equal weights of the substance and of water, and dividing the volume of the latter by that of the former. This leads to a new definition of *specific gravity:* It is *the ratio of the volumes of equal weights of substances, one of which is taken as a standard.* The standard being water, the specific gravity of a substance may be found by dividing the volume of a certain weight of water by the volume of an equal weight of the substance.

As the volumes of cylinders are equal to the products of their bases by their altitudes, it follows that, if the cross-sectional areas of cylinders are maintained constant, their volumes are proportional to their lengths. Thus, in a tube of uniform bore, any length of it is proportional to the volume comprised within that length; the ratio of any two lengths is also the ratio of the corresponding volumes. Use is frequently made of this fact in measuring the volumes of gases and liquids confined in tubes.

What to use. Y-tube with short bits of rubber tubing slipped over two branches and a long piece over the middle branch, which can be closed with a pinch cock. Two glass tubes about a meter long. Two bottles, one containing water and the other kerosene. Meter stick. Stand with clamp.

To determine the specific gravity of a liquid by Hare's method.


HARE'S APPARATUS

What to do. (1) Set up the apparatus as shown in the figure.

(2) Apply the mouth to the end of the long rubber tube, and by suction draw up the liquids until one of them nearly reaches the top. Be careful not to let the liquids flow over through the Y-tube. In case this should happen, throw away the liquid which is thereby contaminated, and take a fresh portion. Close the tube with the pinch cock. If the liquid levels do not remain stationary, there is a leak somewhere. So push the tubes farther into the rubber tubing, coating them with vaseline, castor oil, or glycerine, or binding them with string, if need be.

(3) Set a meter stick vertically beside the tubes and measure to tenths of centimeters the heights above the base of the stand of the liquid surfaces in the bottles as well as in the tubes. Find the lengths of the liquid columns by subtracting the former heights from the latter.

(4) Divide the height of the water column by that of the kerosene column to get the specific gravity of the kerosene.

(5) Change the lengths of the liquid columns a couple of times by letting in or drawing out air, and take readings as above.

(6) What is the force keeping the liquids elevated in the tubes? How do the downward pressures at the higher liquid surfaces compare? And how do the pressures upon the surfaces in the bottles compare? Compare the weights of the two columns of liquid. Which liquid has the greater weight per unit volume, the one composing the shorter or the longer column?

TABULATION

		I	II	III
A	Reading at upper kerosene level	......cm.	......cm.	......cm.
B	" " lower " "	....	....	....
A−B	Length of kerosene column	....	....	....
C	Reading at upper water level	....	....	....
D	" " lower " "	....	....	....
C−D	Length of water column	....	....	....
$\frac{C-D}{A-B}$	Specific gravity found	....	....	....
	Accepted specific gravity	....	....	....
	Per cent of error	....	....	....

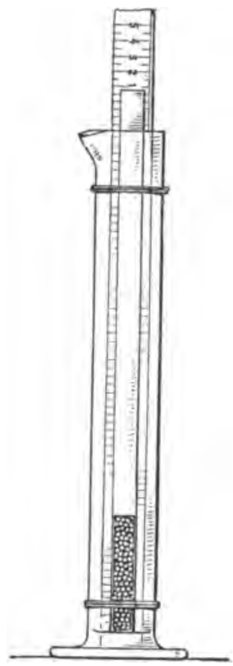
EXPERIMENT XIV

FLOATING BODIES

What to use. Thin-walled glass or aluminum tube closed at one end, and about 1.5 cm. in diameter and 40 to 50 cm. long. A scale engraved on the upper third of the tube or a paper scale (cross-section paper) pasted within the tube, if of glass, is convenient, or the depths of immersion can be measured on a meter stick fastened with string or rubber bands to the outside of the hydrometer jar. $2'' \times 18''$ hydrometer jar. Bullets used in Experiment II. Shot. Balance and weights to decigrams. Vernier or micrometer calipers. Meter stick. Commercial hydrometers. Water and kerosene.

I. *To find out how the pressure of a liquid varies with its depth.*

What to do. (1) Put the least amount of shot into the tube required to make it float vertically when placed in kerosene nearly filling the hydrometer jar. Read the position of the liquid level on the graduated tube. If the tube is not graduated, sight across the bottom of it to the metric scale and note the position of the liquid surface and read also the scale at the surface of the liquid. (See Experiment II.) The difference in these two readings gives the length of the tube immersed.



(2) Remove the tube, wipe it dry, and weigh it and the shot used to decigrams.

(3) Drop a bullet upon the shot and measure how deep the tube now sinks in kerosene. Continue adding bullets until the tube is nearly submerged or strikes the bottom of the jar, measuring after each addition the depth of immersion. The bullets may without appreciable error be taken to have equal weights the same as determined in Experiment V.

(4) Remove the bullets but leave the shot, and repeat (1), (2) and (3) with water, after adding bullets until the tube just assumes a vertical position when floated in the water. Then measure the length of the tube immersed and, adding bullets as before, find the depths of immersion they bring about.

(5) The weight of the tube and its contents make up the downward pressure, which is equal to the upward pressure or buoyant force of the liquid. Divide each total weight by the corresponding depth. How do the quotients compare? In what relationship do pressure and depth stand?

TABULATION

Weights	Readings at bottom of tube	Readings at liquid level	Depths of immersion	$\frac{A}{C-B}$
A	B	C	C−B	
g.	cm.	cm.	cm.	

(Use a similar form for kerosene.)

II. *To test Archimedes' principle for floating bodies.*

(6) Measure with the calipers to hundredths of a centimeter the diameter of the tube in five different places, and from their average calculate its cross-sectional area.

(7) Compute the volumes of water (not kerosene) displaced by the tube by its various loads. Since 1 cm.^{3} of water weighs one gram, the numbers representing these volumes also stand for the numbers denoting the weights of water displaced. How do the loads and the weights of displaced liquid compare?

TABULATION

Diameters cm.	Lengths immersed cm.	Volumes immersed cm.^{3}	Loads g.	Per cents of difference %

III. *To determine the specific gravity of a liquid by the constant-weight hydrometer method.*

(8) It has been seen that for the *same load* the tube sinks deeper in kerosene than in water; it takes a larger volume of kerosene to withstand the same pressure than it does of water. If a denotes the cross-sectional area of the tube, h the length immersed in water and h' the length immersed in kerosene, then the weight of the water displaced is ah, and the weight of kerosene displaced (if s represents its specific gravity) is $ah's$. Since these weights are equal,

$$ah's = ah;$$

whence

$$s = \frac{h}{h'}$$

(9) Divide the depths of immersion in water by the depths of immersion in kerosene for the *same loads*.

TABULATION

Depths in kerosene h' cm.	Depths in water h cm.	Specific gravity of kerosene s

(10) This method of finding specific gravities is rapid and convenient, and several forms of constant-weight hydrometers have been devised for practical use. If one is at hand, check up with it the value you have obtained with the tube.

IV. *To find the specific gravity of a liquid by the constant-volume hydrometer method.*

(11) Add shot until the tube is nearly submerged or almost strikes the bottom of the jar when floated in kerosene. Put a rubber band around the tube to mark the depth to which it sinks. (If the tube is graduated a rubber band will not be necessary.)

(12) Remove the tube from the kerosene, wipe it off without disturbing the rubber band and weigh to decigrams.

(13) Float the tube in water and add shot enough to sink it to the same depth as before. Dry the tube and weigh again.

(14) Divide the weight of the tube and shot when floated in kerosene by the weight of the tube and its contents when floated in water. Compute the per cent of difference between the specific gravity of kerosene obtained by a constant-weight hydrometer and that obtained by a constant-volume hydrometer.

TABULATION

Weight of tube and shot floated in kerosene	g.
" " " " " " " water	g.
Specific gravity of kerosene	
Per cent of difference (referred to constant-weight hydrometer)	%

(15) Show how the results obtained prove that the pressure exerted by a liquid is directly proportional to its density.

EXPERIMENT XV

BOYLE'S LAW

To ascertain how the volume of a gas varies with its pressure, the temperature remaining constant.

First Method

Manometers. A manometer is an instrument for measuring pressure, especially that of a gas. Suppose a vessel to be partly filled with mercury and to be fitted with a thrice perforated stopper, and that a glass tube open at both ends passes through one hole, a tube closed at its upper end passes through a second hole, and that connection is made with an air compressor by the third hole. If the lower ends of the two tubes dip below the surface of the mercury, and air be pumped into the vessel, the compressed air will force the mercury up the tubes. In the case of the open tube, the air within it is pushed out by the mercury, and the height that the mercury rises in such an *open manometer* is a measure of the pressure to which the air in the vessel is subjected. In the case of the closed tube, however, some air is entrapped in it, and the mercury does not rise so high in such a *closed manometer* because of the back pressure of the enclosed air. The volume of the imprisoned air decreases with an increase of pressure; just what the relation between volume and pressure is, this experiment will show.

What to use. Barometer. Boyle's law apparatus, consisting of a bottle fitted with a three-hole stopper. In one hole is inserted a glass tube about 110 cm. long and open at both ends; in another is a tube about 60 cm. long and sealed at its upper end; and in the third hole is an L-tube. The bottle is filled to a depth of about 2 cm. with mercury in which the lower ends of the two straight tubes are immersed. The apparatus is supported on a stand, and a meter stick fastened alongside the tubes. A piece of rubber tubing is slipped over the L-tube and provided with a pinch or screw cock. A bicycle tire valve is inserted in the other end of the rubber tubing to make connections with a bicycle pump. All the connections must be made tight by binding them with cord or wire. A jacketing tube also goes with the apparatus, which when filled with water or steam keeps the air within the closed tube at a constant temperature. This jacketing tube, however, is not essential in this experiment, as the temperature of the room will probably remain constant enough. To prevent the mercury from overflowing a wide tube (broken test tube) is fitted with a cork to the upper end of the open tube.

Boyle's Law Apparatus

What to do. (1) Read the barometer to tenths of a centimeter.

(2) Note to tenths of a centimeter the reading on the meter stick (which must be set vertically) on a level with the inner surface of the upper end of the closed tube. A try square or a draughtsman's triangle or even the square corner of a piece of stiff paper will enable you to make such readings with accuracy.

(3) Carefully work the pump until the mercury in the open tube is forced a little above that in the closed tube and close the cock. Usually the apparatus leaks a little so that the levels of the mercury sink slowly. If such be the case, read the scale when the mercury levels are the same. If the apparatus is tight, however, and the mercury remains stationary, open the cock, unscrew the pump, pinch the rubber tubing tightly with the thumb and finger, and open the valve by sticking a pencil point into it. Cautiously let air escape until the mercury in both tubes is at the same level; then close the pinch cock.

(4) When the mercury stands at the same level in both tubes, the pressure of the confined air is equal to the pressure of the unconfined air; in other words, it is equal to the pressure of the atmosphere. The volume of the confined air may be taken as proportional to the length of the air column. (See Experiment XIII.) The difference between the readings made in (2) and (3) is then the measure of the volume. When the mercury in the open tube is higher than in the closed tube, the pressure on the air is greater than that of the atmosphere; and when it is lower, the air is under a pressure less than that of the atmosphere.

(5) Open the cock and compress the air within the bottle until the mercury in the open tube rises nearly to its top. Close the cock and, if the mercury levels remain stationary, read their positions on the scale. If they should fall slowly, it is possible to hold them stationary long enough to take readings by working the pump slowly. If two students are working together, one can read the mercury in the open tube at the same moment that the other reads the mercury in the closed tube. Open the cock and then the bicycle valve for an instant so that the level of the mercury in the open tube falls about 10 cm. If it should fall much lower than that, pump in a little more air. Continue letting out air and taking readings with differences of pressure amounting to about 10 cm. until the mercury in the open tube comes below the stopper. Add to the barometer reading the difference between the readings on the open and on the closed tubes to get the values of the pressures greater than that of the atmosphere, and subtract that difference to obtain the values of the pressures less than atmospheric.

(6) How do the products of the volumes by the corresponding pressures compare? In what relationship then do the volumes and the pressures of a gas stand? Construct a curve with the volumes laid off on the axis of abscissas and the pressures on the axis of ordinates.

TABULATION

A Barometer reading . . . . cm.
B Reading at top of closed tube . . . . cm.

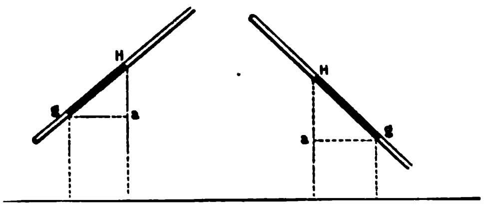
C Readings on open tube.	D Readings on closed tube.	$C-D$ Pressure above atmospheric.	$D-C$ Pressure below atmospheric.	$A+(C-D)$ Pressures P greater than atmospheric.	$A-(D-C)$ Pressures P less than atmospheric.	$B-D$ Volumes V	P × V
cm.	cm.	cm.	cm.	cm.	cm.	cm.	

Second Method

What to use. Meter stick to which is attached a tube with a fine bore closed at one end and containing a certain volume of air imprisoned by a column of mercury. Stand with clamp. Second meter stick. Barometer.

Discussion. Suppose that a tube of narrow bore is sealed at one end and that some air is imprisoned in it by means of a column of mercury. The mercury column may be regarded as a gas-tight piston working without appreciable friction within the tube. The surface of mercury facing the outside air is always under the pressure of the atmosphere. Also when the tube is in a horizontal position, the weight of the mercury is borne by the sides of the tube alone, so that the imprisoned air is likewise under the same pressure as prevails outside. But when the closed end is lower than the open end, the mercury tends to move toward the closed end, thus increasing the pressure upon the confined air; and when the tube is vertical with the closed end down, the weight of the mercury bears down upon the imprisoned air so that the pressure it is under becomes equal to that of the atmosphere plus that of the mercury in the tube. If the pres-

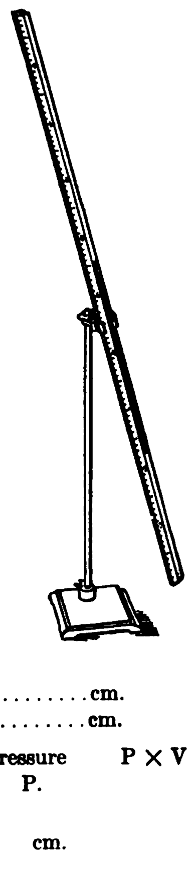
sure of the atmosphere is measured in centimeters of mercury, the length of the mercury column added to the barometric height gives the pressure upon the confined air. Furthermore, when the open end of the tube is tilted downward, the mercury tends to run out and thereby exerts a pull upon the confined air so that its pressure is decreased. When the tube is vertical with the open end down, the pull becomes equal to the weight of the mercury column and the pressure upon the confined air is equal to that of the atmosphere minus that of the column of mercury. With intermediate positions of the tube (see the figure), the increase or decrease of pressure is equal to the vertical distance between the upper and lower levels of the mercury column.



Ha Measures the Pressure

What to do. (1) Clamp the middle of the meter stick bearing the tube to the stand in a horizontal position, horizontality being assured by measuring with the second meter stick down to the level table top equal distances from the ends of the tube.

(2) Measure to millimeters the length of the enclosed air column; this length is proportional to the volume of the confined air under the pressure of the atmosphere, as read off on the barometer.



(3) Loosen the check screw that permits the clamp to turn on a horizontal axis and tilt the closed end of the tube downwards until the mercury has moved 3.0 cm. in the tube. Tighten the screw and measure the length of the air column. Measure the heights of the extremities of the mercury column above the table top. The difference between these heights plus the barometric reading gives the pressure on the confined air. Tilt the tube again so as to move the mercury another 3.0 cm. and take readings. Continue in this way until the tube is nearly vertical.

(4) With the tube held vertically measure the length of the air as well as of the mercury column. The latter length plus the barometric height gives the pressure.

(5) Tilt the open end of the tube downwards, reading the lengths of the air column at intervals of 3.0 cm. and the heights of the ends of the mercury column above the table top. The difference of these heights subtracted from the barometric reading gives the pressure.

(6) Same as (6) in the First Method.

FORM OF RECORD

Height of barometer...cm.
Length of mercury column...cm.

Length of air column V.	Height of mercury from closed end to table top.	Height of mercury from open end to table top.	Difference in heights.	Pressure P.	P × V
cm.	cm.	cm.	cm.	cm.	

EXPERIMENT XVI

SURFACE TENSION

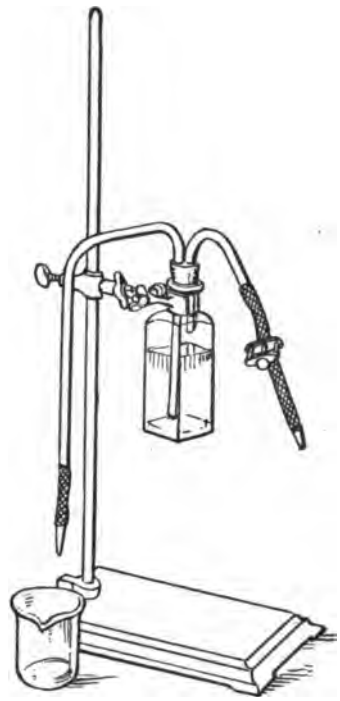
The Drop Method. When a liquid issues slowly from a narrow tube, it forms drops of the same size and weight. A drop falls from the orifice of the tube as soon as its weight just exceeds the surface tension of the liquid all around the orifice. When different liquids drop from the same tube at the same rate, the ratio of the weights of a drop of each is equal to the ratio of their surface tensions. If the surface tension of one liquid is known, that of the other may be computed. For, if the weight of a drop and the surface tension of one liquid be denoted by w and s, and of another liquid by w' and s',

$$\frac{w}{w'} = \frac{s}{s'};$$

and if s' is known,

$$s = \frac{w}{w'} s'.$$

As the value of surface tension decreases with rise in temperature, it is essential that the temperature of the two liquids be the same when their surface tension is measured.



To compare the surface tension of a liquid with that of water by the drop method.

What to use. Bottle fitted with a two-hole stopper through which pass glass tubes bent as shown in the figure. One end of the shorter tube reaches just below the stopper and over its other end is thrust a piece of rubber tubing provided with a screw cock.* The shorter arm of the siphon-shaped tube reaches nearly to the bottom of the bottle and over the other end is pushed a bit of rubber tubing in which the jet tube †

* A good substitute for a screw cock may be readily made as follows: Cut a short slit lengthwise through the rubber tube near its end. By inserting a glass rod, more or less of the slit may be exposed and thereby communication with the outside air may be established or shut off as much as may be desired.

† As most liquids wet glass, there is a tendency for them to creep up around the sides of the tube so that the drops become irregular in size. By coating the tip of the jet tube with wax (beeswax, paraffin or something

is inserted. Stand and clamp. Dish or tumbler. Beaker or similar vessel. Balance with weights to centigrams. Liquid * the surface tension of which is to be compared with that of water. Thermometer.

What to do. (1) Weigh the clean and dry beaker to centigrams.

(2) Rinse out the bottle a couple of times with clear water (distilled is best) and fill it nearly full. The temperature of the water should be that of the room. Thrust the tubes through the stopper and push this into the neck of the bottle. Support the bottle a little above the table top by means of the clamp on the stand. See that the jet tube is inserted so that its axis is vertical.

(3) Open the cock and blow gently with the lips applied to the shorter tube so as to force the liquid through the siphon. Adjust the cock so that the drops fall not faster than about one per second, catching the water in the dish or tumbler.

(4) When a regular rate of flow has been established, catch one hundred drops in the weighed beaker. Then close the cock and weigh the beaker with its hundred drops.

(5) Re-establish the same rate of flow as before and catch another hundred drops without emptying out the first hundred. Find the weight of the beaker and the 200 drops. In like manner find the weight of the beaker and 300 drops.

(6) *Either* empty out the water and rinse out the bottle and tubes with the other liquid, finally filling it with the same, *or* remove the jet tube already used, being careful not to injure its tip, and attach it to another similar bottle filled with the second liquid. Establish as nearly as possible the same rate of drop formation as before, and find in succession the weight of 100, 200, and 300 drops.

TABULATION

		Water	Solution
A	Weight of beaker and 300 drops	g.	g.
B	" " " " 200 drops	g.	g.
C	" " third hundred drops *A–B*	g.	g.
D	" " beaker and 100 drops	g.	g.
E	" " second hundred drops *B–D*	g.	g.
F	" " beaker	g.	g.
G	" " first hundred drops *D–F*	g.	g.
	Average weight of a drop $\frac{C + E + G}{300}$	g.	g.

Surface tension of water at room temperature (page 172, Table V) g./cm.

" " " ________† " " " ....g./cm.

similar) this wetting is prevented in the case of liquids which do not dissolve wax, and the drops are thereby made remarkably uniform in size and weight. To prepare a jet tube, draw out a piece of glass tubing to a diameter of about a millimeter in a Bunsen flame, make a file scratch at the middle of the constricted part A, warm a

Drop from an Uncoated Tube

Drop from a Coated Tube

Preparation of Jet Tubes

little and rub with wax which will melt and coat the tube. Bend the tube a trifle and almost invariably it will break squarely off at the scratch, giving two jet tubes with sharply defined wax coatings at their orifices.

* A moderately concentrated but not saturated solution of some solid, such as salt or sugar, should be used.

† Insert the name of the liquid used.

EXPERIMENT XVII

CONCURRING FORCES

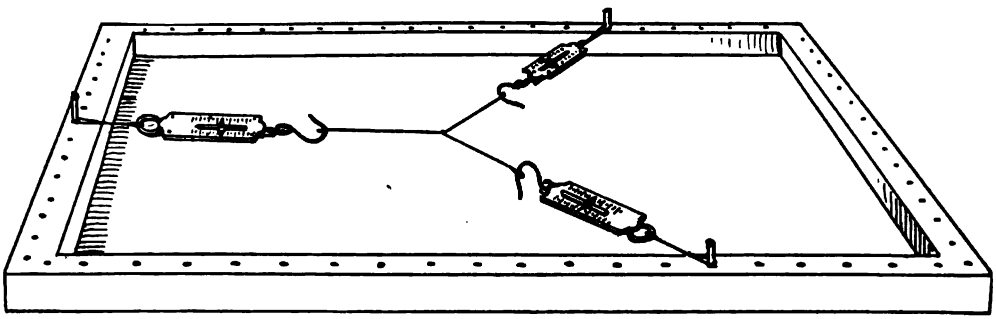
Balanced Forces. The essential items in the description of a force are its magnitude, its direction, and its point of application. The motion of a body due to a single force acting at a certain point in it can be stopped only when a second force equal in magnitude but opposite in direction acts at the same point. Either force is called the *equilibrant* of the other. Two forces of unequal magnitudes acting in opposite directions at the same point in a body make it move in the direction of the greater force.

If two forces act at the same point in a body and if their lines of direction form an angle of less than 180° with each other, the resulting motion is in a direction between the directions of the two forces acting separately, and is the same as would be produced by a single force that is the *resultant* of the two *component forces*. When three forces are in equilibrium, since each has a magnitude, a direction, and a point of application, there are nine measurable things to consider. If they all act at the same point, only six things remain — three magnitudes and three directions.

What to use. General utility board. Three 2000 g. spring balances. Fine but stout cord. Large sheets of paper.

To find out the relationships between the magnitudes and directions of three balanced forces acting at the same point.

What to do. (1) Tie three pieces of cord about 15 cm. long together at one of their ends, and fasten their other ends to the hooks of the balances. Tie cords about 50 cm.



General Utility Board with Accessories for Studying Concurring Forces

long to the rings of the balances. Lay the balances on the general utility board, wind the cords attached to the rings around the pegs and adjust the tensions and directions of the three forces until they form nearly equal angles with one another, when one balance at least is stretched to the limit of its scale.

Spring Balance Corrections. Spring balances are made to be used when hung vertically by their rings. When used in a horizontal position, the spring no longer has to support the weight of the hook and drawbar; consequently the readings are smaller by an amount equal to the weight of the hook and drawbar. The amount of correction to be applied should be determined by reading the balance first in a hanging position and then in a reclining position.

The indexes of some balances are rectangular in shape, so designed that the top of the index gives correct readings when the balance is vertical, while the bottom of the index is to be read when the balance is horizontal.

If the calibration (see Experiment VI) of only one of the balances is known, the others may be quickly calibrated for any of their readings by engaging in succession their hooks in the hook of the calibrated balance and pulling them away from each other until the index of the uncalibrated balance stands at a

reading that was previously obtained. The corrected reading of the calibrated balance is then the true reading of the other balance. Thus, if an uncorrected balance reading were 1825 g., and the corrected reading of a calibrated balance were 1800 g., the latter reading should be substituted for the former.

(2) Lay a large sheet of paper underneath the cords. With the eye *vertically* above the central knot, mark with a sharp pencil a dot directly below the knot. Also make dots vertically below the cords near the edges of the paper. Read the balances, estimating the fifths of the scale divisions, apply the corrections and write down the corrected readings near the corresponding dots.

(3) Remove the paper and draw straight lines from the central dot to the three others. On as large a scale as the size of the paper will permit (such as 1 mm. = 15, 20, or 25 g.), measure off distances on these lines, starting at the central dot, that are proportional to the magnitudes of the forces. Construct a parallelogram on any two of these lines and draw from the central dot a diagonal.

(4) Measure to hundredths of a centimeter the length of this diagonal (*resultant*), and compare it with the length of the line not a part of the parallelogram (that is, the *equilibrant*). How do the directions of resultant and equilibrant compare?

This paper may be bound up in the note-book or an accurate copy of it made by laying it on a sheet of note-book paper and pricking pinholes through it to locate the lines.

(5) *Optional.* Readjust the balances so that the difference of direction of two of the forces is 90° (measured with the aid of the square corner of a piece of paper), while one of the balances is nearly at the limit of its scale. Mark the directions and magnitudes of the forces on a piece of paper as in (3). Construct a rectangle with adjacent sides proportional to the forces including the right angle. Construct its diagonal and compute its length from the lengths of the sides of the rectangle by the Pythagorean proposition. Calculate the per cent of difference between the computed and measured resultants.

EXPERIMENT XVIII

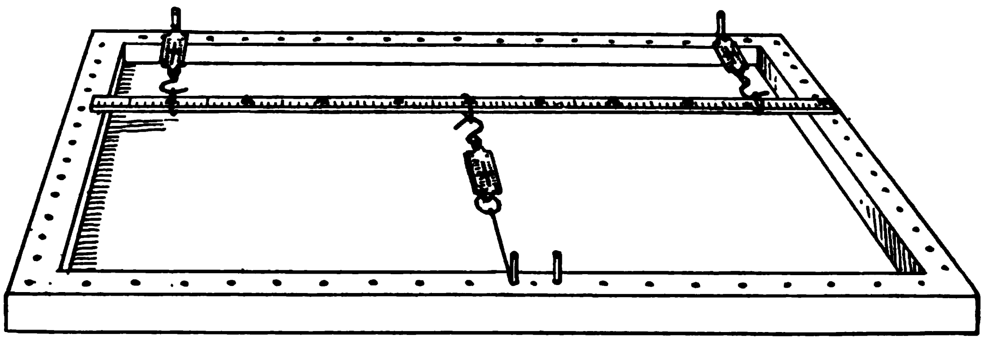
PARALLEL FORCES

Balanced Forces (Continued). By keeping the directions of three forces in equilibrium always parallel, by making one force always the same, and by maintaining a constant distance between the other two forces, there remain out of the nine measurable items for three forces only four, *viz.*, the magnitudes of the two variable forces and the varying distances between their points of application and that of the constant force.

What to use. General utility board. Three 2000 g. spring balances. Meter stick. Fine but strong cord.

To inquire into the conditions of equilibrium of a system of three parallel forces.

What to do. (1) Set two pegs in the general utility board 80 cm. apart and fasten to them the rings of two spring balances. Slip three short loops of cord over the meter



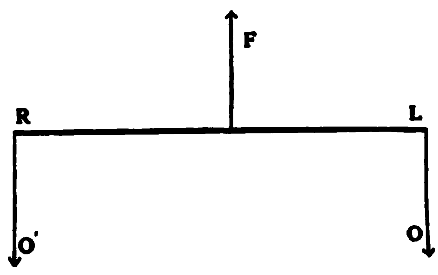
GENERAL UTILITY BOARD WITH ACCESSORIES FOR STUDYING PARALLEL FORCES

stick, insert the hooks of the balances in the two outside loops and the hook of a third balance in the middle loop. Tie a cord about 50 cm. long to the ring of this third balance.

(2) Adjust the loops of the balances 80 cm. apart so that they are on the first and ninth decimeter marks of the meter stick, respectively, and place the loop of the third balance at the second decimeter mark. Stretch the third balance to 2000 g., keeping the lines of direction of the three forces parallel and the meter stick at right angles to the lines of direction. Read the two balances, estimating fifths of divisions, while the third balance shows a reading of 2000 g., applying the balance corrections.

(3) Repeat (2) with the third balance always stretched to 2000 g. but its point of application in succession at the 3d, 4th, 5th, 6th, 7th, and 8th decimeter marks.

(4) How does the magnitude of the third constant force F compare with the sum of the magnitudes of the two variable forces O and O'? How do the products of O and O' by their respective distances from F compare? Form a proportion between the magnitudes of O and O' and the distances LF and RF, as shown in the diagram.



the two moments.* How do they compare? Place the weights in another position and find and compare the moments.

(3) Place both the weights used in (2) on one side of the stick in different positions but near its end.† Hang a 200 g.-weight on the other side in such a position as to produce equilibrium. Compute the three moments, and compare the sum of the two on one side with that on the other. Shift the weights into another position of equilibrium and find and compare the moments.

(4) Putting the weights in different positions as near the ends of the stick as possible, find equilibrium and compute moments when (*a*) a 500 g.-weight is on one side and a 200 g.-weight on the other, and (*b*) when two 100 g.-weights are on both sides.

(5) How do the positive moments compare with the negative moments? State the Principle of Moments. What is the relationship between the magnitudes of the forces and the distances of their points of application from the axis of rotation? Compare this with the relationship found for similar quantities in the experiment on Parallel Forces.

(6) *Optional.* Make up other combinations and compute the moments.

TABULATION†

Positive Forces	Positive Distances	Negative Forces	Negative Distances	Positive Moments	Negative Moments
100 g.	45.0 cm.	g.	cm.	4500	
$\begin{pmatrix}100\\100\end{pmatrix}$†	$\begin{pmatrix}47.0\\44.0\end{pmatrix}$†			$\begin{pmatrix}4700\\4400\end{pmatrix}$†	
etc.	etc.	etc.	etc.	etc.	etc.

* To distinguish between forces which tend to produce rotation in opposite directions, those which move in the same direction as the hands of a clock do, are called positive, and those which move in the opposite direction, negative. Positive forces produce clockwise motion; negative, counter-clockwise motion.

† To indicate that two or more forces are acting simultaneously on one side of the lever, enclose them as well as the corresponding distances in ( ).

EXPERIMENT XX

CENTER OF GRAVITY

Balanced Forces (Concluded). Upon every one of the particles of a body there is exerted an attractive force by the earth. As the directions of these forces are practically parallel, a body may be held in equilibrium, *i.e.*, supported, by a single force which is their equilibrant. The line of direction of this equilibrant is vertical and passes through a certain point of invariable position with respect to the body; this point is known as the *center of gravity*.

I. *To locate the point where the whole weight of a body may be considered to act.*

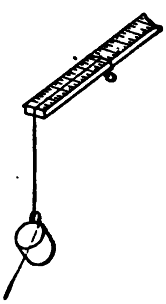
What to use. Meter stick. Balance and weights to decigrams. Fine cord.

What to do. (1) Lay the meter stick flat on the table and slide it slowly over the edge until it begins to turn on the table's edge as an axis. Read to tenths of centimeters the scale directly over the table's edge. Where is the center of gravity of the stick located?

(2) Support the meter stick horizontally on your two extended forefingers held near its ends, and slowly and steadily bring them together until their tips touch. What scale division are the finger tips finally directly opposite? How do you account for the stick's slipping now on one finger and then on the other?

(3) Weigh the meter stick to decigrams.

(4) Tie a 50 g. weight to one end of a piece of cord about 50 cm. long and tie its other end around the meter stick. Letting the cord hang over the end of the stick, balance it over the table's edge as in (1) and read the scale. Where is the center of gravity of the system of bodies composed of the weight and the stick, the weight of the cord being negligible? Taking the edge of the table as the axis of rotation, the moment of the force tending to tip the stick off the table is equal to the product of the 50 g. weight by its distance from the axis. Compute this moment. As the system is in equilibrium, the moment tending to produce rotation in the opposite direction must be equal to the moment just computed. Divide this moment by the weight of the meter stick and compare the quotient with the distance between the center of gravity of the system of bodies and the center of gravity of the meter stick alone. Where may the weight of the stick be assumed to act?



A WEIGHT APPLIED AT THE END OF A METER STICK

(5) Repeat (2) with the weighted meter stick. Where does this method locate the center of gravity of the system?

II. *To locate the center of gravity of a piece of paper.*

What to use. Sheet of note-book paper. Plumb line made of fine thread with a small heavy object, such as a bullet, a button, or something similar attached. Pin or brad. Ruler.

What to do. (6) Stick a pin through one corner of the sheet of paper and then in the end of the table top so that it may swing freely. Hang the plumb line from the pin so that it swings in front of the paper but does not touch it. Make a dot near the lower edge of the paper directly behind the thread, when both plumb line and paper are at rest.

(7) Repeat (6) with the pin stuck through an adjacent corner.

(8) Draw lines from each of the pin holes to the corresponding dots. Their point of intersection marks the position of the center of gravity, actually halfway between the two surfaces of the paper.

(9) Turn the paper over and repeat (6), (7) and (8) on the other side. Stick a pin through the paper at the point of intersection and see how close it comes to the point of intersection on the other side.

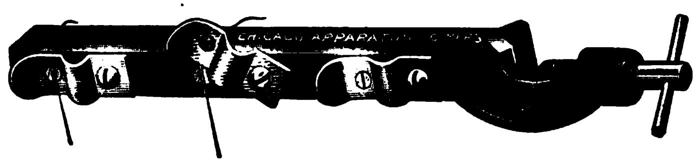
(10) Tear off one corner of the paper and relocate its center of gravity. The paper may be bound up in your note-book as a record of the experiment.

EXPERIMENT XXI

PENDULUMS

Definitions. The *period* of a pendulum is the time it takes to swing from one side to the other, and is found by dividing the time occupied by the pendulum in making a certain number, such as 100, of vibrations by that number of vibrations. The *length* of a pendulum is the distance between its centers of suspension and of oscillation. If the pendulum consists of a body (bob) hung by a cord the mass of which is negligibly small in comparison with the mass of the bob, its center of oscillation coincides with its center of mass or gravity, and if the bob has a regular geometrical form, as that of a sphere or cylinder, its center of gravity is at the center of figure. The *amplitude* is the wideness or extent of swing.

What to use. A metal and a wooden ball to which are attached fine cords or wires for suspension. The tendency that twisted cord or thread has to untwist may be prevented in a measure by rubbing it with beeswax or shoemaker's wax. Stand or other support for suspending the pendulum. A good form of suspension is the following: Cut a lengthwise slit halfway through a cork of medium size and put it between the jaws of



the clamp attached to the stand. The cord is inserted in the slit and the cork squeezed in the clamp so that the friction keeps the cord from slipping. An excellent form of clamp is shown in the figure. Time-measurer such as a clock with a seconds-hand, a stop-watch, or even an ordinary watch. (The clock may be connected with a telegraph sounder so as to give a click every second, or a metronome may be used.) Calipers. Meter stick.

I. *To ascertain what influence the amplitude of the swing of a pendulum has upon its period.*

What to do. (1) Measure to tenths of a centimeter the diameters of the balls.

(2) Suspend one of the balls so that the length of the cord between the point of suspension and the top of the ball plus the radius of the ball is 60.0 cm. Lay the meter stick underneath the ball in the plane of the swinging of the pendulum.

(3) (*For one student.*) Pull the ball about 5 cm. to one side of its vertical position and let go. Standing directly in front of the support and with the clock or watch in plain view, note the time in *hours, minutes*, and *seconds*, as 10 *hr.* 25 *min.* 18 *sec.*, or start the stop-watch at the instant the pendulum passes through its vertical position. Count 100 passages through that position, and again note the time, or stop the watch. Make three trials and take their average.

(*For two students, A and B.*) A pulls the ball about 5 cm. to one side of its vertical position and lets go. Standing directly in front of the support, A counts when the pendulum passes through its vertical position as follows: 3-2-1-*GO*-1-2-3 and so on. B notes the time in *hours, minutes, and seconds*, as 10 *hr.* 25 *min.* 18 *sec.*, the instant he hears the word GO. A continues counting silently until the 97th vibration is reached,

when he counts aloud 7-8-9-STOP. B notes the time again when he hears the word STOP. Take the average of three trials.

(4) Divide the time by the number of vibrations to get the period.

(5) Repeat (3) with the ball pulled (*a*) 10 cm. aside and (*b*) 15 cm. aside. How do the averages of the periods for the different amplitudes compare? What influence has the amplitude upon the period?

II. *To ascertain what effect the material or mass of the bob has upon the period.*

(6) Repeat (2) to (5) with the other ball as the pendulum bob, being very careful to have the length the same as before. What influence does the material or the mass of a pendulum have upon the period?

III. *To find the relationship between the length and the period of a pendulum.*

(7) Determine the period (average of three trials) of a pendulum as long as possible. Let the bob hang down over the edge of the table to the floor, using two meter sticks with their ends overlapping to measure the length.

(8) Find the period (average of three trials) of a pendulum one-fourth as long as the one used in (7).

(9) Divide the squares of the periods of the pendulums by the corresponding lengths. How do the periods and lengths vary? Show how all the facts and relationships may be resumed in the formula

$$t = \pi\sqrt{\frac{l}{g}},$$

where t denotes the period, l the length, and g the acceleration due to gravity (980 cm. sec.^{3}). Compute the value of g from the values you have obtained for l and t.

TABULATION

Diameter of pendulum bob made of ____________ *........................cm.

l Length of Pendulum	Length of Arc	A Beginning Time *Hr.*	*min.*	*sec.*	B Ending Time *Hr.*	*min.*	*sec.*	$B-A$ Time of 100 Vibrations	$\frac{B-A}{100}$ Period t	$\frac{t^2}{l}$
60.0 cm.										

* Insert the name of the substance.

EXPERIMENT XXII

FRICTION

What to use. General utility board or a smooth board about 25 cm. wide and 100 cm. long. Smooth block about 5x10x15 cm. with a screw eye in one end. 2000 g. spring balance. Several kilogram weights (canvas bags filled with sand, shot, or small iron washers are excellent). Stout cord.

To study the laws of sliding friction and to find the coefficient of sliding friction.

What to do. (1) Tie the hook of the balance to the screw eye of the block by a short piece of cord and determine the weight of the block.*

(2) Lay the broadside of the block on the board and load it with a weight of 2 kg. The pressure between the block and the board is equal to the weight of the block together with that of its load. Draw the block slowly and steadily along the board, and read the balance at least three times while it is moving uniformly. Record the average of these readings as the force required to overcome the friction. What effect does moving the block at different rates have on the value of the force of friction?

(3) Repeat (2) with loads of 4 kg. and 6 kg.

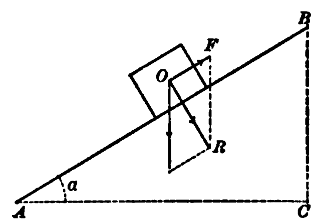
(4) Repeat (2) and (3) with the block placed on one of its narrow sides. How do the areas of contact compare in this position and in the other position of the block? How do the corresponding values of the friction compare? What effect does area have upon the value of sliding friction?

(5) Compute the coefficient of sliding friction for each trial by dividing the force of friction by the pressure between the two surfaces.

(6) *Optional.* Repeat the experiment with blocks of different materials or with the same b ock rubbing on a surface of different material, such as an unvarnished table top.

(7) *Optional.* Tilt up one end of the board until the block resting upon it slides down slowly with uniform velocity. Measure to tenths of a centimeter the height BC and the base AC of the right triangle of which the board occupies the position of the hypothenuse AB. Calculate the coefficient of sliding friction from these measurements.*

Friction on an Inclined Plane. Suppose a smooth block to be placed upon a board that is then gradually tilted upward until the block slides slowly downward. The force of friction in that case equals the force that would have to be applied upward, in a direction parallel to the board, in order to check the motion. The weight of the block may be resolved into two components, one perpendicular and the other parallel to the board. The perpendicular component OR represents the pressure between the block and the board; and the parallel component OF, the force of friction. Since the triangle ROF is similar to the triangle ABC,



FRICTION ON AN INCLINED PLANE

$$\frac{OF}{OR} = \frac{BC}{AC}.$$

The coefficient of sliding friction is defined to be the ratio of the force required to slide two surfaces past each other to the pressure between the surfaces. Hence the coefficient of friction $= \dfrac{OF}{OR}$.

The angle a is called the *limiting angle of friction*, and is the greatest angle at which a plane can be inclined to the horizontal without another plane sliding on it. The coefficient of friction between small pieces of the same material determines the angle presented by heaps of them, as is seen in piles of coal, of grain, etc.

* Apply in all the work the balance corrections (see Experiments VI and XVII).

TABULATION

Substances Rubbed Together	Pressure	Friction on Broad Side	Coefficient of Sliding Friction	Friction on Narrow Side	Coefficient of Sliding Friction
	g.	g.		g.	

EXPERIMENT XXIII

THE INCLINED PLANE

Machines. The mechanical advantage of a machine is the ratio of the resistance to the effort. The velocity ratio is the ratio of the distance traversed by the effort to that traversed by the resistance in the same time. The amount of energy delivered to a machine is equal to the product of the effort F by the distance l through which the effort moves, and the amount of work delivered by a machine is the product of the resistance R by the distance l' through which it moves. If there is no friction,

$$\frac{R}{F} = \frac{l}{l'}.$$

All actual machines, however, work with friction; hence the need of an expression to indicate the proportion of the energy delivered to a machine that is expended in overcoming friction. Efficiency is the ratio of the work delivered by a machine to the work delivered to it. Efficiencies are expressed as percentages. If a certain machine, for example, has an efficiency of 90 per cent, 10 per cent of the energy delivered to it is employed in overcoming the friction of its moving parts.

In the two simple machines here studied, the effect of friction may be practically eliminated by reversing the action of the machine. Thus, when the effort pulls the resistance up an inclined plane or raises it by means of a pulley system, the effort has to overcome the friction, but when the resistance pulls the effort down on an inclined plane or raises it by means of a system of pulleys, it is the resistance that overcomes the friction. The average of the values of the effort, as measured in the direct and reverse actions, gives the value of the effort required to hold the resistance in equilibrium, the effect of friction being eliminated.

In calculating the mechanical advantage, friction must be regarded as eliminated, while in computing the efficiency, it must be taken into consideration.

To compare the mechanical advantage of an inclined plane with certain of its dimensions.

What to use. Inclined plane adjustable to different angles.* 2000 g. spring balance, or balance pan with box of weights to be used with a pulley fastened to the plane. Car (a roller skate will answer). Several kilogram weights.† Stout cord. Meter stick.

What to do. (1) Adjust the plane so as to make an angle of about 30° with the horizon. Suspend the car from the spring balance to find its weight. Load the car with enough weights to bring the balance reading nearly to the limit of its scale when it is holding the car on the plane. The load or resistance is equal to the weight of the car and of what it contains.

(2) Applying the force parallel to the plane, haul the loaded car slowly and steadily up the plane, noting the reading on the balance. Let the car roll down at the same rate it ascended, and note the balance reading.‡ Half the sum of these readings gives the value of the effort required to support the resistance on the plane with friction eliminated.

(3) Measure to tenths of a centimeter the length and the height of the plane.

(4) The weight of the car together with its load makes up the resistance. Divide the resistance by the effort to get the mechanical advantage. How does the mechanical advantage compare with the ratio of the length to the height of the plane? If the car were lifted straight up with uniform velocity through a distance equal to the height of the

* The general utility board, a smooth board about a meter long or a factory-made inclined plane may be used. One end of the plane may be propped up on blocks or hung up by cords from a support, if the plane is not furnished with a special device for adjusting its slant.

† Large iron nuts or washers or canvas bags filled with sand or small iron washers will answer.

‡ If a fixed pulley and balance pan with weights are used, put enough weights on the pan to pull the car slowly up the plane, and then remove weights until the car descends at the same rate.

plane and then hauled up the plane with uniform velocity, how much greater would the latter velocity be than the former, provided the times taken for both motions were the same? What then is the velocity ratio?

(5) The work in gram-centimeters expended upon the inclined plane is equal to the product of the force needed to haul the load *up* by the length of the plane; and the work accomplished with the aid of the plane is equal to the product of the resistance by the height of the plane. To find the efficiency, divide the latter amount of work by the former, and multiply the product by 100 so as to get it as a percentage.

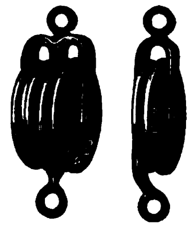
(6) *Optional.* Repeat the experiment with the plane inclined at an angle of about 45°.

TABULATION

	30°	45°
Weight of the load R	g.	......g.
Effort with load rising F_u	g.	......g.
Effort with load descending F_d	g.	......g.
Effort with friction eliminated $(F_u + F_d) \div 2 = F_a$	g.	......g.
Length of the plane L	cm.	......cm.
Height of the plane H	cm.	......cm.
Mechanical advantage R/F_a		......
Ratio of the length of the plane to its height L/H		......
Velocity ratio		......
Work delivered to the machine $F_u \times L$	g./cm.	......g./cm.
Work delivered by the machine $R \times H$	g./cm.	......g./cm.
Efficiency $(R \times H) \div F_u \times L$	%	......%

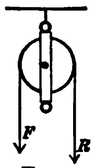
EXPERIMENT XXIV*

PULLEYS



What to use. A single and a double pulley. A double pulley turning with considerable friction (two spools nailed loosely between two wood strips will answer). 2000 g. spring balance. One 1 kg. weight and one 3 kg. or two 2 kg. weights (canvas bags filled with sand, shot, or iron washers, sewed tight and furnished with a loop of cord will do). Stand with clamp, or other support. Stout cord. Meter stick.

To find the mechanical advantage and efficiency of various pulley combinations.



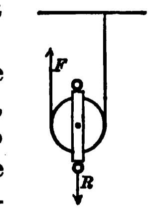
FIXED PULLEY

What to do. (1) (*Fixed Pulley.*) Suspend the single pulley from the support and pass a cord over it, to one end of which is attached the one kilogram weight and to the other the *hook* of the spring balance.†

(2) Pull down on the balance and take a reading while the weight is steadily rising. The actual force is equal to the pull exerted by the hand plus the weight of the balance. Since the balance is upside down, its reading takes into account both the hand's pull and the balance's weight. Let the weight descend at the same rate and note the balance reading. The average of the two balance readings gives the force (effort) required to hold the weight (resistance) in equilibrium, the influence of friction being eliminated. How does the effort compare with the resistance in this case? How many parts of the cord are supporting the load? What is the mechanical advantage?

(3) Measure to tenths of a centimeter the vertical distance that the effort moves over while the resistance is being moved a certain distance, such as 10 or 20 cm., up or down. How do the two distances compare?

(4) The work in gram-centimeters done on the pulley is equal to the product of the effort when hauling the load *up* by the distance through which it moves while the load moves 20 or 30 cm. as the case may have been in (3), and the work done by the pulley is equal to the product of the load by the distance through which it moves. Compute the efficiency.



MOVABLE PULLEY

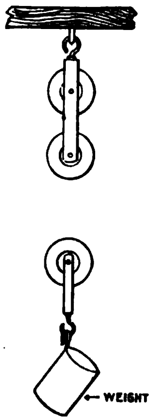
(5) (*Movable pulley.*) Arrange the single pulley as indicated in the figure. Whenever a movable pulley is used it becomes a part of the load, and its weight should be determined by the spring balance and added to that of the load. Hold the balance right side up and suspend 3 kg. from the pulley hook. How many parts of the cord are supporting the load? Determine the mechanical advantage, velocity ratio, and efficiency as in the case of a fixed pulley.

(6) Hang the double pulley that has but slight friction from the support and 4 kg. from the single pulley. Arrange them in a system suggested by the figure of a three-sheave pulley having the balance upside down and the cord passing around all three of the sheaves (wheels). How many parts of the cord support the load? Find and compare the values of the mechanical advantage and the velocity ratio. Find also the efficiency.

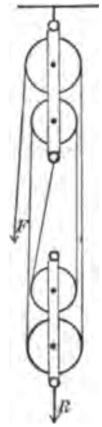
* See *Machines* on page 59.

† Whenever the spring balance is used in pulling downwards, attach it upside down to the cord so that the reading it gives will include its own weight, and consequently no correction because of its position (except that for the weight of the hook) will have to be applied.

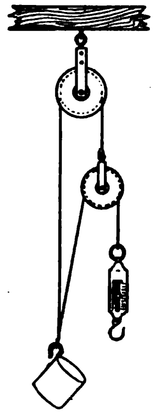
(7) Hang the double pulley with much friction from the support and 4 kg. from the other double pulley. Pass the cord around all four sheaves and find the mechanical advantage and velocity ratio. How do they compare with each other and with the number of cords passing from the fixed to the movable block? Find the efficiency and tell why it has such a different value from those found for the previous cases.



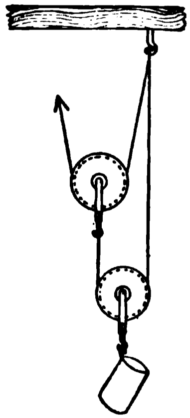
THREE-SHEAVE PULLEY



FOUR-SHEAVE PULLEY



SPANISH BURTON



RUNNER AND TACKLE

(8) *Optional.* Rig up a Spanish burton and also a runner and tackle, using a load of 3 kg., and find the mechanical advantage, velocity ratio and efficiency of each.

TABULATION

	Fixed Pulley	Movable Pulley	Three-Sheave Pulley	Four-Sheave Pulley	Spanish Burton	Runner and Tackle
Weight of the load R	g.	g.	g.	g.	g.	g.
Effort with load rising F_u	g.	g.	g.	g.	g.	g.
Effort with load descending F_d	g.	g.	g.	g.	g.	g.
Effort with friction eliminated $(F_u + F_d) \div 2 = F_a$	g.	g.	g.	g.	g.	g.
Mechanical advantage R/F_a						
Distance effort moves l	cm.	cm.	cm.	cm.	cm.	cm.
Distance resistance moves l'	cm.	cm.	cm.	cm.	cm.	cm.
Velocity ratio l/l'						
Number of parts of cord						
Work delivered to the machine $F_u \times l$	g./cm.	g./cm.	g./cm.	g./cm.	g./cm.	g./cm.
Work delivered by the machine $R \times l'$	g./cm.	g./cm.	g./cm.	g./cm.	g./cm.	g./cm.
Efficiency $(R \times l') \div (F_u \times l)$	%	%	%	%	%	%

EXPERIMENT XXV

FIXED POINTS OF A THERMOMETER

What to use. Thermometer inserted in a perforated cork. Stand with two rings and a clamp. (I) Tumbler or dish filled with clean snow or crushed ice. (II) Flask* supported on a wire gauze set on a ring of the stand, with a second ring encircling the upper part of the flask to steady it. Bunsen burner. Barometer.

I. *To test the accuracy of the freezing point mark of a thermometer.*

What to do. (1) Secure the cork in the clamp at such a height that the bulb of the thermometer comes somewhat below the center of the tumbler set upon the base of the stand. Pack the ice or snow cautiously but snugly around the bulb and the stem as far up as the freezing point mark.

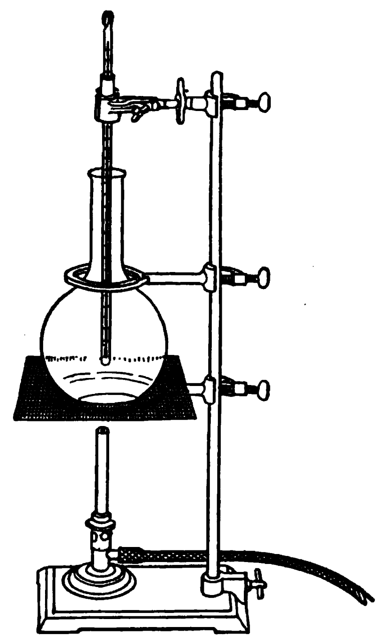
(2) Read the position of the mercury on the scale, estimating the tenths of a degree, at intervals of a few seconds until the mercury remains stationary. If the reading is below the zero mark, put a minus sign before it, as, for example, — .3°.

II. *To test the accuracy of the boiling point mark.*

(3) Fill the flask or boiler nearly a fourth full of water, and heat it to boiling. Suspend the thermometer in the neck of the flask so that its bulb is a centimeter or so above the surface of the water. Read the thermometer at frequent intervals until the mercury is stationary.

(4) Read the barometer and subtract its reading from 76, the standard pressure in centimeters of mercury. It has been found that an increase of one centimeter in barometric pressure raises the boiling point of water by .37°. Its true boiling point is then equal to the product of .37 by the difference between 76 and the barometer reading, added to 100°, if the barometer reads above 76 cm., and subtracted from 100°, if below 76 cm. Find the error in the boiling point mark of your thermometer by taking the difference between its reading and the true boiling point as computed.

(5) *Optional.* Immediately after having tested the boiling point, test the freezing point again. Is it the same as at first? If possible, repeat the freezing point test a day or so later. Can you draw any conclusion as to the reliability of low temperature readings on a thermometer that has been recently exposed to a high temperature?


APPARATUS FOR TESTING BOILING POINT

* A factory-made boiler may be used instead of the flask and stand.

TABULATION

Graduation of thermometer No. —— extends from ——° to ——°	°
Observed freezing point	°
Error in the location of the freezing point mark	°
Barometer reading	cm.
Observed boiling point	°
True boiling point	°
Error in the location of the boiling point mark	°

EXPERIMENT XXVI

LINEAR EXPANSION

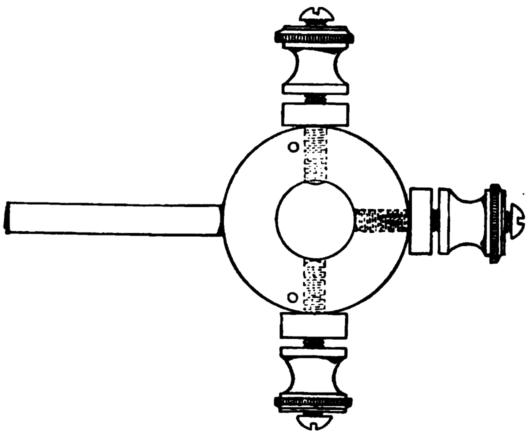
Coefficient of Linear Expansion. Suppose that a rod having a length l at the temperature t is heated to the temperature t', and that its length at this higher temperature becomes l'. The average increase in length or the expansion of the rod is $l' - l$; and its expansion per unit of length is $\frac{l'-l}{l}$. The expansion per degree of temperature per unit length is

$$\left(\frac{\frac{l'-l}{l}}{t'-t}\right) = \frac{l'-l}{l} \quad \frac{1}{t'-t} = \frac{l'-l}{l\,(t'-t)}.$$

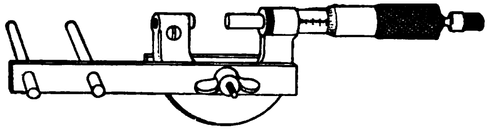
The number obtained by substituting the numerical values found by experiment in the above formula is called the *coefficient of linear expansion* for the substance used.

The determination of this coefficient requires the measurement of two temperatures and of two lengths. In practice, however, only one length and the expansion are measured, the same degree of accuracy being observed in both measurements. For example, a brass rod about 1000 mm. long expands somewhat less than 2 mm. when it is heated from the temperature of the room to that of boiling water. Since measurements with a micrometer caliper are not sure beyond hundredths of a millimeter, an error of about .5 per cent is unavoidable in measuring the expansion of 2 mm. Hence it is unnecessary to measure the length of the rod with a greater degree of accuracy than about .5 per cent. An error of 5 mm. in the measurement of the length would not therefore affect the final result any more than would an error of .01 mm. in the measurement of the expansion.

What to use. General utility board. Thermometer. Brass or aluminum tube about 110 cm. long. Three peg-and-collar clamps. Micrometer caliper with a clamp to



PEG-AND-COLLAR CLAMP



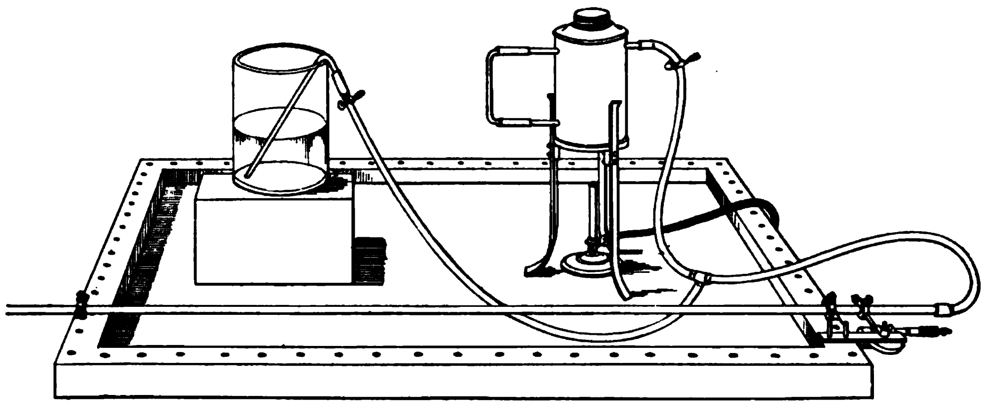
MICROMETER CALIPER CLAMP

fasten it to the board. Boiler and Bunsen burner (a glass flask supported on a ring stand will do). T- or Y-tube and four pieces of rubber tubing. Jar or can of water set upon a box or other support. Second jar or a basin. Glass siphon. Two pinch cocks. Meter stick. (If the micrometer is not provided with a ratchet stop, a battery and bell with connecting wires will be required.*)

*__Battery and Bell Method.__ Strip the insulation from the ends of the wires and scrape the metal bright. Wind several tight turns of the bared portion of one wire around the tube and connect its other end to the battery. In like manner wrap one end of another wire around the U-shaped part of the micrometer, and connect its other end to the bell. A third wire connects the battery to the bell. The battery should be strong enough to make the clapper of the bell vibrate vigorously.

*To determine the coefficient of linear expansion of ———.**

What to do. (1) Set up the apparatus as shown in the figure. The peg-and-collar clamp farthest from the micrometer must be fastened tightly to the tube, while the set screws of the other peg-and-collar clamp that is inserted in the board must not touch the tube. By such an arrangement the expansion will be toward the micrometer only. Attach the micrometer to the board in such a way that the peg of the third peg-and-collar clamp will come between the jaws of the micrometer near the fixed jaw;



General Utility Board with Accessories for Measuring Linear Expansion

tighten up the screws on both clamps so as to hold the peg and the micrometer firmly in these positions. Connect the tube with the boiler and the siphon by means of the T-tube as shown, putting a pinch cock on the rubber tubes, close to the boiler and to the siphon, respectively. Attach a rubber tube to the other end of the metal tube, and let it hang down over the edge of the table so that the water after passing through the apparatus may be caught in a jar or basin set on the floor.

(2) Stir the water thoroughly in the jar with the thermometer and take its temperature to tenths of a degree. Open the siphon pinch cock and close the boiler pinch cock. By suction applied to the end of the outlet tube, start the siphon so that a brisk current of water may run through the tube and bring it to the temperature of the water as read in the jar.

(3) Turn the screw of the micrometer until it presses against the peg of the clamp with just sufficient force to make the ratchet click or the bell ring. Read the micrometer, estimating the thousandths of a millimeter. Repeat this adjustment twice, and take the average of the three readings as the "lower micrometer reading."

(4) Measure with a meter stick to millimeters only the distance between the center of the farthest peg-and-collar clamp and the outside of the peg of the nearest clamp where the tip of the micrometer screw makes contact.

(5) Turn the screw of the micrometer back a couple of millimeters to make room for the expansion of the tube. Close the siphon pinch cock and open the boiler pinch cock. Get up steam in the boiler and pass it through the tube.

(6) Adjust the micrometer to contact as in (3). Take three readings and record their average as the "higher micrometer reading."

(7) Find the temperature of the steam (which is the same as that of the tube) by

* Insert the name of the substance used.

putting the thermometer in the neck of the boiler, or by computations based on the barometric reading. (See Experiment XXV.)

(8) Repeat the determination with the farthest peg-and-collar clamp inserted in one of the holes in the longer side of the frame of the general utility board, thus making the part of the tube the expansion of which is measured somewhat shorter.

TABULATION

	I	II		I	II
Lower micrometer reading ...	mm.	mm.	Higher micrometer reading ...	mm.	mm.
	mm.	mm.		mm.	mm.
	mm.	mm.		mm.	mm.
Average	mm.	mm.	Average	mm.	mm.

	I	II
Expansion of tube	mm.	mm.
Length of tube made of ——*	mm.	mm.
Higher temperature	°	°
Lower temperature	°	°
Change of temperature	°	°
Coefficient of linear expansion of ——*	..	..
Accepted value	..	..
Percentage of error	%	%

Second Form of Apparatus

Instead of a tube, a rod passing through perforated corks inserted in the ends of a jacketing tube may be used. An excellent form of such an apparatus is shown in the

figure, in which the micrometer screw is made an integral part of one of the supports. The operations are similar to those given for the tube form; the water and then the steam is passed through the jacketing tube, and the micrometer adjusted to measure the expansion.

* Insert the name of the substance of which the tube is made.

EXPERIMENT XXVII

EXPANSION COEFFICIENTS OF AIR

Expansion of Gases. When a gas is heated in a closed vessel of constant volume, its pressure increases as the temperature rises. The ratio of the increase in pressure per degree to the pressure at 0° is called the *pressure coefficient of expansion*. Denoting the pressure of the gas at 0° by p_o and at $t°$ by p_t, the increase in pressure is $p_t - p_o$, and the increase per degree is $\frac{p_t - p_o}{t}$. The pressure coefficient c_p is therefore

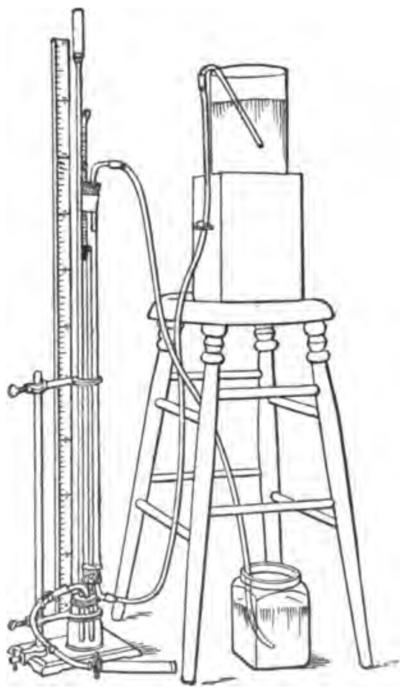
$$c_p = \frac{p_t - p_o}{p_o\, t}.$$

If the gas when heated is free to expand and is subjected to a constant pressure, its volume increases as the temperature rises. If v_o and v_t denote its volume at 0° and $t°$, respectively, the *volume coefficient of expansion* is defined to be

$$c_v = \frac{v_t - v_o}{v_o\, t}.$$

To determine (a) *the volume coefficient of expansion,* (b) *the pressure coefficient of expansion of air.*

What to use. Boyle's law apparatus (see Experiment XV) with jacketing tube. Flask and stand, or boiler for generating steam. Two cans or battery jars, one filled with cracked ice and water to which enough salt has been added to lower the temperature to about $-2°$. Glass siphon tube fitting over the side of the jar or can. Rubber tube provided with a screw cock connecting the boiler or siphon with the jacketing tube. Thermometer. Bunsen burner. Barometer.



What to do. (1) Read the barometer to tenths of a centimeter.

(2) Connect the lower L-tube of the jacketing tube with the siphon hanging over the side of the jar or can that contains the ice water. Set the ice water holder on a box or other support so that its bottom is a little above the top of the jacketing tube. Apply suction to the rubber tubing joined to the upper L-tube of the jacketing tube, and start the siphon to flowing, catching the water that flows through the jacketing tube in the second jar or can, which should also contain some ice so as to keep the water cold in case it has to be passed a second time through the apparatus. Read the meter stick where it is on a level with the inner surface of the upper end of the closed tube.

(3) When the thermometer inserted through the upper stopper of the jacketing tube stands at 0°, pinch the outflow tube together a little with the cock, so as to regulate the flow and maintain a temperature of 0°, and work the bicycle pump until the mercury level in both tubes is the same. Read the position of the mercury on the scale. Repeat this adjustment and reading twice. The average of these readings

subtracted from the reading made in (2) may be taken as the volume of the confined air at 0° under the prevailing atmospheric pressure as read in (1).

(4) Substitute the boiler for the supply of ice water and pass steam into the upper L-tube, letting it escape from the lower L-tube through a rubber tube hanging over the edge of the table, and catching the drip in a jar.

(5) When the temperature is stationary, pump air into the apparatus until the mercury stands at the same level in both tubes and take a reading. Repeat this determination twice. The average subtracted from the reading made in (2) gives the volume of the air at the higher temperature under atmospheric pressure.

(6) Work the pump until the mercury in the closed tube stands at the same level as it did in (3), and read the position of the mercury in the open tube, making three adjustments. The difference between these readings gives the increase in pressure required to compress the air at the higher temperature into the same volume it occupied at 0°.

(7) Compute the volume coefficient and the pressure coefficient, and find the percentage of difference between the values and the accepted value.

(8) *Optional.* Repeat the above determinations.

TABULATION

			I	II
A	Barometer reading		cm.	cm.
B	Reading at the top of the air column		cm.	cm.
C	Reading of the mercury level in both tubes when the air is at 0°.	1st adjustment	cm.	cm.
		2d "	cm.	cm.
		3d "	cm.	cm.
		Average	cm.	cm.
t	Temperature when steam is passed		°	°
D	Reading of the mercury level in both tubes when the air is at $t°$.	1st adjustment	cm.	cm.
		2d "	cm.	cm.
		3d "	cm.	cm.
		Average	cm.	cm.
E	Reading on the open tube when the temperature of the air is $t°$ and the reading on the closed tube is the same as in C	1st adjustment	cm.	cm.
		2d "	cm.	cm.
		3d "	cm.	cm.
		Average		
F	Volume of the air at 0° and A cm. $[B - C]$		cm.	cm.
G	Volume of the air at $t°$ and A cm. $[B - D]$		cm.	cm.
	Increase in volume under pressure of A cm. $[G - F]$		cm.	cm.
	Coefficient of expansion under constant pressure $\left[\frac{G - F}{F t°}\right]$			
	Accepted value		.00367	.00367
	Per cent of error		%	%
A	Pressure of the air with volume constant at 0°		cm.	cm.
H	Pressure of the air with volume constant at $t°$ $[E - C + A]$		cm.	cm.
	Increase in pressure with constant volume $[E - C]$		cm.	cm.
	Coefficient of expansion with constant volume $\left[\frac{H - A}{A t°}\right]$			
	Accepted value		.00367	.00367
	Per cent of error		%	%

EXPERIMENT XXVIII

SPECIFIC HEAT

Method of Mixtures. Let m_1 g. of a substance having a specific heat s_1 and at the higher temperature t_1 be mixed with m_2 g. of a second substance the specific heat of which is s_2, and which is at the lower temperature t_2; let the temperature of the substances after mixing be t. The first substance will lose an amount of heat represented by $m_1 s_1 (t_1 - t)$, while the second substance will gain an amount of heat denoted by $m_2 s_2 (t - t_2)$. If all the heat given out by the first substance is received only by the second substance, these two heat quantitites are equal, so that

$$m_1 s_1 (t_1 - t) = m_2 s_2 (t - t_2).$$

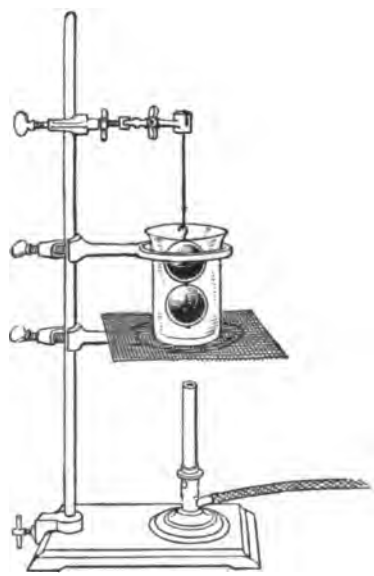
If any six of the seven quantities figuring in this equation are determined experimentally, the seventh one may be computed.

First Method

To determine the specific heat of a liquid by mixing it with a metal of known specific heat.

What tc use. Two or three metal drilled balls strung on a thick wire with one end bent into a hook, or a large metal sphere or cylinder with hook. Hooked wire with which to handle the string of balls or cylinder. Calorimeter. It is well to have it supported in an outer vessel by a wood or hard rubber ring. A 400 cm.^{3} glass beaker set in a tin can makes a good calorimeter. Stand with two rings, wire gauze and clamp. Bunsen burner. Thermometer. Balance with weights to decigrams. Kerosene.*

What to do. (1) Find the weight m_1 of the cylinder or spheres to decigrams, attach the hooked wire, and suspend from the clamp in water contained in a can or beaker set on wire gauze upon a ring of the stand. Heat the water to boiling with the burner. Find the temperature t_1 of the boiling water.



Apparatus for Heating the Metal (Calorimetric Body)

(2) Determine the weight m_3 of the calorimeter to decigrams.

(3) Fill the calorimeter about three-fourths full of kerosene and weigh it. Take the temperature of the kerosene, cooling it, if necessary, to about 10° by immersing the calorimeter in cold water, or by setting it outside the window, if the weather is cold.

(4) Set the calorimeter in the outer vessel, stir the kerosene well with the thermometer and read the temperature to tenths of a degree t_2. Right after reading the temperature, bring the calorimeter near the stand where the metal is being heated, and without a second's delay transfer the hot metal to the kerosene. Remove the wire, stir the kerosene with the thermometer, reading it at intervals of a few seconds until the mercury ceases to rise. The final temperature t should be read with great care.

(5) Compute the weight m_2 of the kerosene by subtracting the weight m_3 of the calorimeter from the weight of the calorimeter filled with the kerosene. Also compute

* Any liquid such as turpentine and toluene, which is not too volatile, may be used instead of kerosene.

the change of temperature (t_1-t) of the metal and that $(t-t_2)$ of the kerosene. The calorimeter is likewise heated from t_2 to t so that the amount of heat it receives is equal to its mass m_3 multiplied by the product of its change of temperature and its specific heat $m_3\, s_3\, (t-t_2)$. Denoting by s_2 the specific heat of kerosene, the amount of heat it receives is $m_2\, s_2\, (t-t_2)$, and denoting by s_1 the specific heat of the metal, the amount of heat it gives out is $m_1\, s_1\, (t_1-t)$. The amount of heat received by the thermometer may without appreciable error be neglected, so that

$$m_1\, s_1\, (t_1 - t) = m_2\, s_2\, (t - t_2) + m_3\, s_3\, (t - t_2).$$

s_1, the specific heat of the metal, and s_3, the specific heat of the material of which the calorimeter is made, are given in Table IX of Appendix A. Hence the only unknown in the equation is s_2, the specific heat of the kerosene. Rearranging the equation, we have

$$s_2 = \frac{m_1\, s_1\, (t_1 - t) - m_3\, s_3\, (t - t_2)}{m_2\, (t - t_2)}.$$

Substitute the known values for the quantities in the last equation and compute the specific heat of kerosene.

TABULATION

		I	II
m_1	Weight of the metal *	g.	g.
	" " " calorimeter and kerosene	g.	g.
m_3	" " " calorimeter	g.	g.
m_2	" " " kerosene	g.	g.
t_1	Temperature of the metal	°	°
t_2	" " " kerosene and calorimeter	°	°
t	" " " " " metal after mixing	°	°
	Change of temperature of the metal $(t_1 - t)$	°	°
	" " " " " calorimeter and kerosene $(t - t_2)$	°	°
s_1	Specific heat of the metal		
s_3	" " " " calorimeter made of ——— †		
	Amount of heat given out by the metal $m_1\, s_1\, (t_1 - t)$	cal.	cal.
	" " " received by the calorimeter $m_3\, s_3\, (t - t_2)$	cal.	cal.
s_2	Specific heat of kerosene		
	Accepted value for the specific heat of kerosene		
	Percentage of error	%	%

* Insert the name of the metal.
† Insert the name of the substance.

Alternative Method

What to use. *Alternative apparatus.* Aluminum pellets, sheet copper clippings, or lead shot. Wide test tube and tall beaker, or dipper with boiler.

What to do. (1*a*) Weigh the test tube or dipper to decigrams. Fill it nearly full of the pieces of metal and weigh again. The increase is the weight m_1 of the metal. Fill the beaker nearly full of water, set it on a wire gauze upon a ring stand, and put the test tube in the water. The depth of the water should be at least equal to the depth of the metal. If a dipper is used, set it in the boiler filled to a depth of an inch or so with water. Insert a thermometer in the metal and cover over with cotton wool to keep out drafts. Boil the water gently and read the temperature at intervals of a minute or so.

(2*a*) Find the weight m_3 of the calorimeter to decigrams.

(3*a*) Fill the calorimeter about three-fourths full of kerosene and weigh. When the temperature of the metal has remained stationary for at least three minutes, record it t_1, remove the thermometer and put it in the kerosene. Cool the kerosene, if necessary, to about 10° by immersing the calorimeter in cold water or by setting it outside the window, if the weather is cold.

(4*a*) and (5*a*) are the same as (4) and (5), allowance being made for the difference in apparatus.

SECOND METHOD

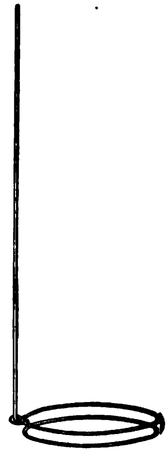
To determine the specific heat of a liquid by mixing it with water.

What to use. Same as in the First Method with the exception of the metal and wire, and with the addition of a stirrer and a second beaker.

What to do. (6) Pour about 300 cm.³ of water into a beaker, set it on a piece of wire gauze placed over a ring of the stand, and put a Bunsen burner under the gauze. Heat the water with a small flame.

(7) In the meantime weigh the calorimeter together with the stirrer to tenths of a gram, fill it about three-fifths full of kerosene and weigh again. Place the thermometer in the liquid, and lower the temperature to about 10° by setting the calorimeter in cold water or outside the window, if the weather is cold. Wipe off the outside of the calorimeter and set it within the outer can.

(8) Put the thermometer (or use a second one, if available) into the water, and as soon as its temperature is between 50° and 60°, remove the flame.



STIRRER

(9) Wipe off the thermometer, place it in the kerosene, and take its temperature t_2 to tenths of a degree, stirring it well. Do not delay performing (10), else the temperature of the kerosene may change.

(10) Put the thermometer again in the water and note its temperature t_1 to tenths of a degree, stirring thoroughly. As the temperature falls rapidly, it is advisable to wrap the vessel of water in a dry cloth. *Immediately* after noting its temperature, pour the hot water rapidly but cautiously into the calorimeter until it is filled to within a couple of centimeters of the top.

(11) Work the stirrer up and down through the surface separating the two liquids, so as to make them come to the same temperature as quickly as possible. After stirring for about a minute, put the thermometer into the kerosene, noting the temperature, and then into the water below, again reading the temperature. If these two temperatures are not identical, continue stirring until the thermometer shows no temperature difference when immersed in one and then in the other liquid. Denote this common temperature by t.

(12) Remove the thermometer, take the calorimeter out of the enveloping vessel, and weigh it together with its contents.

(13) Find the weight m_2 of the kerosene by subtracting the weight m_3 of the calorimeter from the weight of the kerosene and calorimeter (including the stirrer), and the weight m_1 of the water by subtracting the weight of the kerosene and calorimeter from the weight of the water, kerosene, and calorimeter (stirrer included). Calculate the change of temperature $(t-t_2)$ of the kerosene and calorimeter, and that of the water

(t_1-t). The amount of heat received by the calorimeter is equal to its weight m_3 multiplied by the product of its change of temperature $(t-t_2)$ and its specific heat s_3; that is, $m_3 s_3 (t-t_2)$. The amount of heat received by the thermometer and by the stirrer may be regarded as negligible. Hence, as all of the heat of the water in cooling from t_1 to t may be considered as having warmed the kerosene and calorimeter from t_2 to t, if the specific heat of the kerosene be denoted by s_2, that of water by s_1, and that of the material of which the calorimeter is composed by s_3,

$$m_1 s_1 (t_1 - t) = m_2 s_2 (t - t_2) + m_3 s_3 (t - t_2).$$

The specific heat of water is unity and that of the material of which the calorimeter is made is given in Table IX of Appendix A. Hence the specific heat of kerosene is the only unknown quantity in the equation. Rearranging it we have

$$s_2 = \frac{m_1 s_1 (t_1 - t) - m_3 s_3 (t - t_2)}{m_2 (t - t_2)}.$$

Substitute the known values for the quantities in the equation and solve for s_2.

TABULATION

		I	II
	Weight of the calorimeter, stirrer, kerosene * and water	g.	g.
	" " " " and kerosene	g.	g.
m_1	" " " water	g.	g.
m_3	" " " calorimeter and stirrer	g.	g.
m_2	" " " kerosene	g.	g.
t_1	Temperature of the water	°	°
t_2	" " " calorimeter and kerosene	°	°
t	" " " water and kerosene after mixing	°	°
	Change of temperature of the water $(t_1 - t)$	°	°
	" " " " " calorimeter and kerosene $(t - t_2)$		
s_1	Specific heat of water	1	1
s_3	" " " calorimeter made of ——— †		
	Amount of heat given out by the water $m_1 (t_1 - t)$	cal.	cal.
	" " " received by the calorimeter $m_3 s_3 (t - t_2)$	cal.	cal.
s_2	Specific heat of kerosene		
	Accepted value for the specific heat of kerosene		
	Percentage of error	%	%

* Substitute the name of the liquid actually used.
† Insert the name of the substance composing the calorimeter.

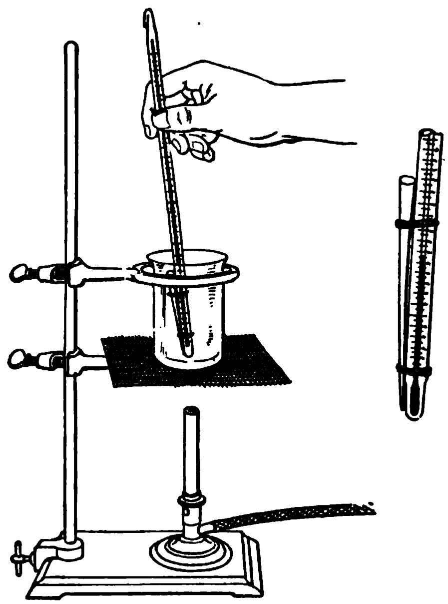
EXPERIMENT XXIX

MELTING POINT

What to use. Stand with two rings and gauze. Bunsen burner. Beaker. Thermometer. Thin-walled glass tubing. Triangular file. Rubber rings cut from a piece of hose. Menthol. (Diphenylamin and thymol are also good substances to use, but not paraffin, as it is a mixture of substances and does not have on that account a definite melting point.) Tumbler or beaker full of cold water.

To determine the melting point of a solid by the capillary tube method.

What to do. (1) Hold with both hands a piece of glass tubing about 10 cm. long horizontally in the top part of a Bunsen flame (or better in the flame of a fish-tail burner) and rotate it until its center becomes red hot. Remove it from the flame and without delay steadily draw it out into a tube with a bore of about a millimeter. Break off this capillary tube with the help of a file, and seal one end of it by holding it in a flame for a moment or so.



THE WAY TO ATTACH THE CAPILLARY TUBE TO THE THERMOMETER IS SHOWN BY THE RIGHT-HAND FIGURE

(2) Powder some of the substance finely with a knife blade and fill the capillary tube about a quarter full of it, tapping gently so as to make the powder settle down into the closed end.

(3) By means of rubber rings, fasten the tube to the thermometer so as to bring the substance alongside the bulb of the thermometer.

(4) Fill the beaker about three-fourths full of clear water, set it upon the gauze resting upon one ring of the stand, and arrange the other ring so that it will encircle the

beaker and prevent it from falling off. Light the burner and, using a flame of medium size, begin to heat the water.

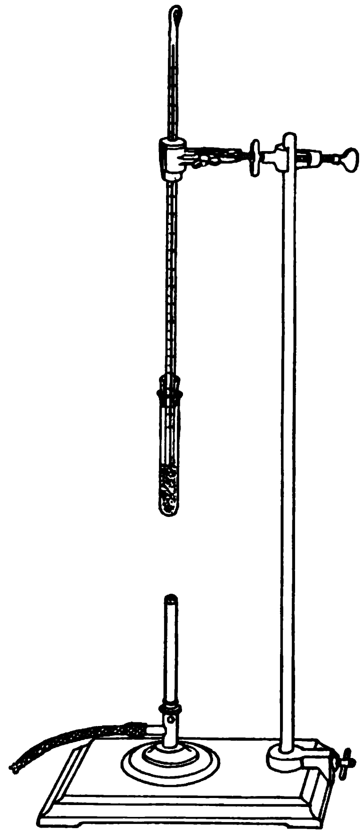
(5) Stir the water with the thermometer and attached tube, keeping close watch upon the substance. As soon as this begins to melt, remove the flame, and stir well for a few seconds. If the solid does not all melt, heat it a little more. When the solid has melted, remove the thermometer and cool the substance by blowing upon it or by immersing it in cold water until the substance solidifies again. Pour a little cold water into the beaker, place the thermometer and attached tube in it, and stir thoroughly. If the substance melts promptly, the temperature of the water is above its melting point, and more cold water must be added. If, on the other hand, it does not melt, heat the water a little. Raise the temperature of the water by applying the flame, or lower it by adding cold water, until the substance, when introduced into the well stirred water, takes at least thirty seconds to melt entirely. Read the thermometer to tenths of a degree. The temperature is the melting point of the substance.

EXPERIMENT XXX

COOLING THROUGH A CHANGE OF STATE

Undercooling. When a definite chemical substance in the solid state is heated, it always begins to melt at a certain temperature, which remains constant until the solid is all melted. But when the melted substance is cooled, the temperature at which it begins to solidify is seldom, if ever, precisely the same as the melting point. Certain solids can be cooled much below their melting points before solidification ensues, while others can be undercooled but slightly. Crystallization will always, however, take place at the melting point if any (a minute fragment is enough) of the solid be added to the melted substance. As soon as solidification once commences, the temperature of the undercooled liquid rises to the melting point, and remains constant until all the liquid has solidified; solidification is a heat-evolving process.

Examples of substances that cannot ordinarily be undercooled very much are naphthalene (80°), acetanilide (115°) and diphenylamin (54°). Examples of substances that undergo considerable undercooling are sodium thiosulphate (48°) (the hyposulphite of soda or hypo of the photographer) and acetamide (82°).



What to use. A 4-in. test tube fitted with a cork through which passes a thermometer, a slice being cut out of the cork just wide enough to expose the scale; the thermometer is also thrust through another cork to hold it in a clamp. Stand with clamp, rings, and gauze arranged for boiling water in a beaker. One of the substances mentioned above. Watch.

To plot the curve of cooling of a substance melting at a temperature between the temperature limits of the curve.

What to do. Fill the test tube half full of the solid, and set it in boiling water until it is entirely melted. Pass the thermometer through the cork and insert the cork firmly in the tube so that the bulb of the thermometer reaches nearly to the bottom of the tube and is entirely surrounded by the melted substance.*

(2) Immerse the bulb again in the boiling water until the mercury in the thermometer comes to a standstill. Then suspend the thermometer with attached tube from the clamp, and note the temperature at intervals of 30 seconds.

(3) Record the temperature at which crystals begin to form. Continue noting the temperatures at intervals of 30 seconds or one minute until the temperature is about 20° below the melting point of the substance.

(4) Do not try to pull the thermometer out of the solidified substance in which it is imbedded. Melt the substance first and then remove the thermometer.

(5) Plot a curve with temperatures as ordinates and times as abscissas. Give an explanation for the form of the curve.

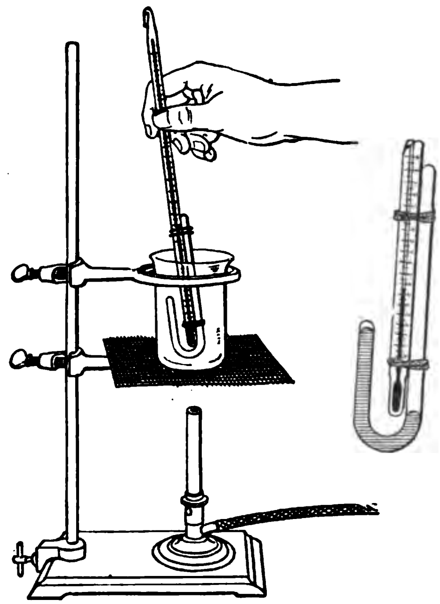
* If a thermometer graduated above 100° or provided with a bulb above the 100° mark is used, the substance may be melted by the direct application of a small flame instead of by immersion in boiling water.

EXPERIMENT XXXI

BOILING POINT

The Boiling Point. When a liquid is heated to a temperature where its vapor tension becomes equal to the pressure of the atmosphere, it is at its boiling point. If the liquid be in an open vessel heated from below, bubbles of vapor will form at the bottom of the liquid and, rising to the top, pass out into the air. But if the liquid be confined in a vessel provided with an open manometer or pressure gauge, the temperature of both the vapor pressure and atmospheric pressure will be shown by the gauge.

What to use. U-tube with its short arm closed. Enough mercury is introduced into this gauge to fill the short arm and to reach around the bend. A little acetone (ether, alcohol, carbon tetrachloride, or other suitable liquid may be used) is poured into the gauge, and, by inclining the tube, a drop or so of it is made to displace the mercury and to rise up into the closed end. *No air should be in the closed arm.* The gauge is attached to a thermometer by means of two bands cut from a piece of rubber tubing. Stand with two rings and a wire gauze upon which rests a beaker. Bunsen burner. Metric rule. Barometer.



THE WAY TO ATTACH THE GAUGE TUBE TO THE THERMOMETER IS SHOWN IN THE RIGHT-HAND FIGURE

To find the boiling point of a liquid by the vapor tension method.

What to do. (1) Measure to tenths of a millimeter the distance between the 0° and the 100° marks on the thermometer. One hundredth of this distance is the length in millimeters of one of the thermometer divisions. Read the barometer.

(2) Set up the apparatus as shown in the figure, filling the beaker about three-fourths full of clear water. Heat with a small flame, and stir the water with the thermometer and attached gauge. As soon as the mercury begins to rise in the open arm

because of the vaporization of the liquid, remove the flame, and, if the mercury continues to rise even after thorough stirring, remove the U-tube. Pour a little cold water into the beaker, replace the U-tube, stir well, and note the behavior of the mercury. By alternate heating or by adding cold water, get the temperature of the bath such that the level of the mercury in both arms is the same. Put the tube very cautiously into the water and keep close watch, for if the temperature is too high, the vapor pressure will be great enough to push the mercury out of the gauge. How does the pressure of the vapor compare with the pressure of the atmosphere when the mercury stands at the same level in both arms? Read the temperature to tenths of a degree; it is the boiling point of the liquid.*

(3) The boiling point found is that for the prevailing pressure of the atmosphere. The boiling point at the standard pressure of 760 mm. of mercury is determined by increasing or decreasing the pressure upon the vapor by an amount equal to the difference between 760 and the barometric reading, as set forth in (4).

(4) Place the gauge in the water and adjust its temperature until the mercury in the open arm is as many millimeters above (in case the barometric reading is less than 760) or below (in case the barometric reading is more than 760) the mercury in the closed arm as there are millimeters in the difference between 760 and the barometric reading. As the length of a thermometer division has been determined in millimeters, this measurement can be made by the aid of the thermometric scale. The temperature is then the boiling point of the liquid under a pressure of 760 mm. of mercury.

TABULATION

Distance between 0° and 100° on the thermometer	mm.
Length of one thermometer division....................................	mm.
Barometer reading	mm.
Boiling point of ———† under barometric pressure	°
Boiling point of ———† under 760 mm.	°

* **Superheating.** Just as a liquid may be cooled below its point of solidification without the formation of crystals, so may it be heated above its boiling point without the formation of vapor. The main conditions to be realized in both cases are (1) freedom from jars or shocks; (2) absence of the solid or vapor, respectively. If the liquid is *superheated*, that is, is heated above its boiling point, when vaporization does take place finally, it may do so with explosive violence. To prevent such an explosion from projecting the mercury out of the gauge, it is well to have a bulb blown in the open arm.

† Insert the name of the liquid used.

EXPERIMENT XXXII

HEAT OF FUSION

Latent Heat of Fusion. A gram of water at 0° differs from a gram of ice at 0° mainly in that the water contains more heat energy than does the ice; how much more it is the purpose of this experiment to determine. If m_1 g. of hot water at the temperature t_1 is mixed with m_2 g. of ice at 0°, and if just enough hot water is used to melt the ice, the final temperature will be 0°. The amount of heat given out by the water will be $m_1\,t_1$ calories, and if l denote the number of calories required to melt one gram of ice,

$$m_1\,t_1 = l\,m_2;$$

whence

$$l = \frac{m_1\,t_1}{m_2}.$$

It is difficult, however, to regulate the amounts of ice and of water, as well as the temperature, so as to melt the ice exactly. As a rule, the ice is not only melted, but the resulting water is also warmed. If m_1 g. of water at t_1 are mixed with m_2 g. of ice at 0°, and if, after the ice is all melted, the resulting temperature is t, the hot water has given out $m_1\,(t_1 - t)$ cal., of which $m_2\,l$ cal. have melted the ice, and $m_2\,t$ cal. have warmed the melted ice to the temperature t. The calorimeter will also have the temperature t_1, and, if its mass is m_3 g. and its specific heat s_3, it will give out $m_3\,s_3\,(t_1 - t)$ cal. Hence

$$m_1\,(t_1 - t) + m_3\,s_3(t_1 - t) = m_2\,l + m_2\,t.$$

Rearranging the equation we have

$$l = \frac{m_1\,(t_1 - t) + m_3\,s_3(t_1 - t) - m_2\,t}{m_2},$$

or

$$l = \frac{(m_1 + m_3\,s_3)(t_1 - t) - m_2\,t}{m_2}.$$

To determine how many calories are required to change one gram of ice at 0° into one gram of water at 0°.

What to use. Calorimeter and stirrer (see Experiment XXVIII). Thermometer. Balance and weights to decigrams. Supply of clean ice and of hot water. Dry cloth or plenty of blotting or filter paper.

What to do. (1) Find the weight m_3 of the calorimeter to tenths of a gram. Fill it about four-fifths full of water at about 50° and weigh it. The increase in weight is the weight m_1 of the hot water.

(2) Place the calorimeter in its outer vessel and take the temperature t_1 to tenths of a degree, stirring the water well with the stirrer.

(3) Directly after reading the temperature drop in lumps of ice without splashing, wiping each lump dry immediately before adding it.

(4) Keep stirring the water and ice, noting the temperature every few seconds. Add enough ice to lower the temperature, after it is all melted, to about 10°. Read the final temperature t to tenths of a degree.

(5) Weigh the calorimeter and contents. The increase in weight over that found in the second weighing in (1) is the weight m_2 of the ice used.

(6) Add the amounts of heat given out by the hot water $m_1\,(t_1 - t)$ and by the calorimeter $m_3\,s_3\,(t_1 - t)$, taking the value for the specific heat of the material composing the calorimeter from Table IX in Appendix A. Subtract from their sum the amount of heat $m_2\,t$ used in warming the melted ice from 0° to t. Divide the remainder by the weight m_2 of the ice. Find the percentage of difference between your value and the accepted value.

TABULATION

		I		II
	Weight of calorimeter, water, and ice	g.	......	g.
	" " " and water	g.	......	g.
m_3	" " ice	g.	......	g.
m_2	" " calorimeter	g.	......	g.
m_1	" " water	g.	......	g.
t_1	Temperature of hot water and calorimeter	°	......	°
t	" " water and ice after melting	°	......	°
	Change of temperature of water and calorimeter $(t_1 - t)$	°	......	°
	" " " " melted ice t	°	......	°
s_2	Specific heat of calorimeter made of ______*	°	......	°
	Amount of heat given out by the water $[m_1 (t_1 - t)]$	cal.	......	cal.
	" " " " " " " calorimeter $m_2 s_2 (t_1 - t)$	cal.	......	cal.
	" " " received by the melted ice $(m_3 t)$	cal.	......	cal.
l	Latent heat of fusion of ice	cal.	......	cal.
	Accepted value for the latent heat of fusion of ice	80 cal.	......	80 cal.
	Percentage of error	%	......	%

* Insert the name of the substance of which calorimeter is made.

EXPERIMENT XXXIII

HEAT OF VAPORIZATION

Latent Heat of Vaporization. To convert water into steam requires the expenditure of heat energy the amount of which depends upon the temperature at which the conversion takes place. When steam is condensed into water, precisely the same amount of heat is given out as was needed to turn the water into steam, provided, of course, the conditions are identical. The heat of condensation is equal to the heat of vaporization.

Suppose that m_1 g. of steam at the temperature t_1 are mixed with m_2 g. of water at the lower temperature t_2. If L represent the heat of condensation (number of calories given out when one gram of steam condenses into one gram of water at the same temperature) and if the water is thereby heated from t_2 to t_1 the number of calories received by the water may be denoted by $m_2\,(t_1 - t_2)$ and

$$L\,m_1 = m_2\,(t_1 - t_2),$$

whence

$$L = \frac{m_2\,(t_1 - t_2)}{m_1}.$$

Ordinary experimental conditions are such, however, that the water cannot be heated up to the temperature of the steam but only up to a lower temperature t. The condensed steam is therefore cooled from t_1 to t, thereby giving out an amount of heat represented by $m_1\,(t_1 - t)$. Also the calorimeter is heated from t_2 to t, so that, if its mass is m_3, and its specific heat is s_3, it absorbs $m_3\,s_3\,(t - t_2)$ cal. Neglecting the heat absorbed by the thermometer, we have

$$L\,m_1 + m_1\,(t_1 - t) = m_2\,(t - t_2) + m_3\,s_3\,(t - t_2),$$

whence

$$L = \frac{m_2\,(t - t_2) + m_3\,s_3\,(t - t_2) - m_1\,(t_1 - t)}{m_1},$$

or

$$L = \frac{(m_2 + m_3\,s_3)\,(t - t_2) - m_1\,(t_1 - t)}{m_1}.$$

To determine how many calories are given out when one gram of steam is condensed into one gram of water, both at the boiling point of water.

I. Method of Mixtures

What to use. Calorimeter (see Experiment XXVIII). Thermometer. Flask * set on wire gauze placed over a ring of a stand and connected by a rubber hose with a trap. (The trap catches the water condensed when the steam passes through the rubber tubing, thereby insuring the dryness of the steam leaving the delivery tube.) Bunsen flame giving a large amount of heat. Balance with weights to decigrams.

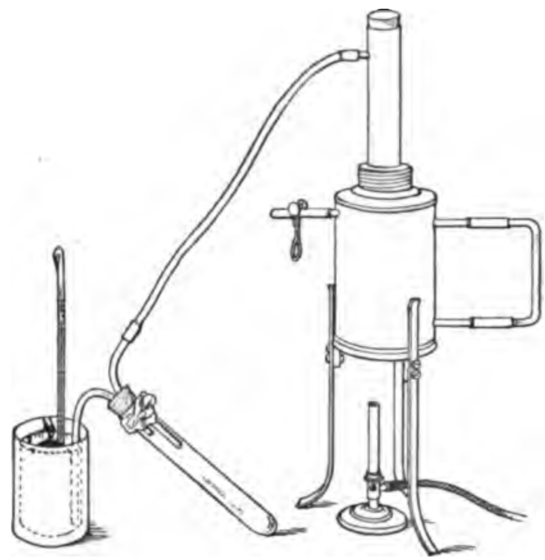
What to do. (1) Find the weight m_3 of the calorimeter to tenths of a gram. Fill it about four-fifths full with water at about 10° and weigh again. The increase in weight gives the weight m_2 of the water. Set the calorimeter in its outer vessel and remove it from the vicinity of the flame.

(2) Get up steam in the boiler and let the delivery tube send the current of steam down over the edge of the table. A piece of cloth or paper wrapped around the trap makes it easy to handle. It is essential that the supply of steam be abundant. The temperature of the steam t_1 may be found by immersing a thermometer in it through the neck of the flask or by computations based on the barometric pressure. (See Experiment XXV.)

(3) Stir the water in the calorimeter with the thermometer and take its temperature t_2. Leaving the thermometer in the water, pass *at once* to (4).

* A factory-made boiler may be used instead.

(4) Rapidly place the end of the delivery tube a couple of centimeters below the surface of the water and stir briskly. If the steam in condensing does not make a loud noise, it is not being generated fast enough; so place a second burner under the boiler. When the temperature rises to about 35°, take away the delivery tube and remove the calorimeter from the immediate vicinity of the flame. Stir the water and take its temperature t.



(5) Take out the thermometer, draining it as thoroughly as possible, and weigh the calorimeter with its contents. Its increase in weight is equal to the weight m_1 of the condensed steam.

(6) Compute the latent heat of vaporization by the aid of the formula given above. Find the percentage of difference between your value and the accepted value of 536 cal.

TABULATION

		I	II
	Weight of the calorimeter, water and steam	g.	g.
	" " " " and water	g.	g.
m_1	" " " steam at t_1	g.	g.
m_2	" " " water at t_2	g.	g.
m_3	" " " calorimeter at t_2	g.	g.
	Change of temperature of water and calorimeter $t - t_2$	°	°
	" " " " condensed steam $t_1 - t$	°	°
s_3	Specific heat of calorimeter made of ——*		
	Amount of heat given out by the condensed steam $m_1 (t_1 - t)$	cal.	cal.
	" " " received by the water $m_2 (t - t_2)$	cal.	cal.
	" " " received by the calorimeter $m_3 s_3 (t - t_2)$	cal.	cal.
L	Latent heat of vaporization of water at t_1		
	Accepted value for the latent heat of vaporization of water	536 cal.	536 cal.
	Percentage of error	%	%

* Insert the name of the substance composing the calorimeter, looking up its specific heat in Table IX of Appendix A.

II. Steam Calorimeter Method

The Steam Calorimeter. Let m g. of a substance having a specific heat s and at the temperature $t°$ be introduced into steam at t'. The substance will be heated by the steam up to the temperature t', whereby m' g. of the steam will be condensed upon the substance. The quantity of heat given out by the steam in condensing will be equal to the product of its latent heat L and its mass m', that is, $L\,m'$ cal., and the quantity of heat received by the substance may be denoted by $m\,s\,(t' - t)$. Then

$$L\,m' = m\,s\,(t' - t),$$

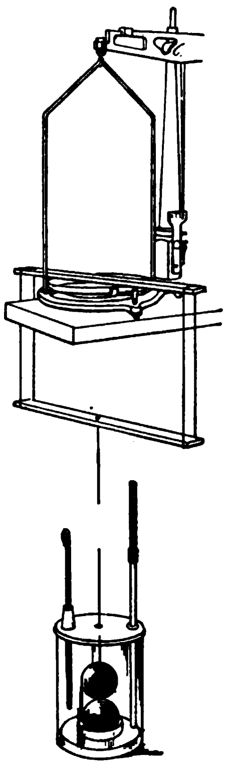
whence

$$L = \frac{m\,s\,(t' - t)}{m'}.$$

What to use. Beam balance with weights to centigrams. Board somewhat narrower and longer than the base of the balance. Heavy weight or table clamp. Two lath-like sticks a little longer than the width of the balance base. Fine wire or cord. Steam calorimeter made of a battery jar with a loose cover pierced with three holes. Calorimetric body consisting of two drilled balls through which passes a stout wire having a shallow pan soldered to its lower end; the pan is to catch the condensed steam. Boiler connected by a rubber tube to a straight glass tube reaching to the floor. Pinch cock on the rubber tube. Thermometer. Bunsen burner.

To find how much steam is condensed upon a body of known mass and specific heat when heated through a certain temperature interval; to find the latent heat of vaporization by the steam calorimeter method.

What to do. (1) Lay the board upon the table so that one of its ends extends a foot or so over the edge of the table top. Clamp the other end fast or lay a heavy weight upon it. Set the balance on the board so that its pillar is about even with the edge of the table. Fasten the laths together with loops of string or wire as shown, and suspend from the lower one the calorimetric body by a wire or thread long enough to permit the body to hang nearly to the bottom of the calorimeter set on the floor.



(2) Remove the calorimetric body and weigh the suspension laths and wires to centigrams. Thread the suspension wire of the calorimetric body through the center hole of the calorimeter cover, attach the body, and weigh again, adjusting the position of the calorimeter, if needs be, so that the suspension wire will not rub against the sides of the hole in the cover. Put the thermometer through another hole alongside the body.

(3) Pinch the tube together, which connects the boiler to the calorimeter, but leave some opening in the boiler so that the steam may escape until needed. Put the delivery tube through the third hole in the cover so that its end reaches nearly to the bottom of the calorimeter but does not touch the suspended calorimetric body. Place a burner under the boiler, and when the steam is issuing freely, read the thermometer in the calorimeter to tenths of a degree, thus getting the lower temperature t of the calorimetric body. Open the pinch cock and close the other opening so as to make the steam pass into the calorimeter.

(4) After steam has been passed into the calorimeter for a minute or so, place weights upon the balance pan so as to restore equilibrium, adjusting the calorimeter, if necessary, in order to prevent the suspension wire from rubbing against the sides of the hole. When the weight is constant, read the thermometer to get the temperature t' of the steam and then remove the burner from under the boiler.

(5) The specific heat of the calorimetric body is given in Table IX in Appendix A. Multiply the mass m, the specific heat s, and the change of temperature $t'-t$ of the body together, and divide this product by the mass m' of the steam. The quotient is the latent heat of vaporization of water.

TABULATION

	I	II
Weight of the calorimetric body, laths, wires, and condensed steam	g.	g.
" " " " " " and wires	g.	g.
" " " laths and wires	g.	g.
" " " calorimetric body	g.	g.
" " " steam condensed	g.	g.
Temperature of the steam	°	°
" " " calorimetric body	°	°
Change of temperature	°	°
Specific heat of the calorimetric body made of ______*		
Latent heat of vaporization of water	cal.	cal.
Accepted value for the latent heat of vaporization of water	536 cal.	536 cal.
Percentage of error	%	%

* Insert the name of the substance composing the calorimetric body.

EXPERIMENT XXXIV

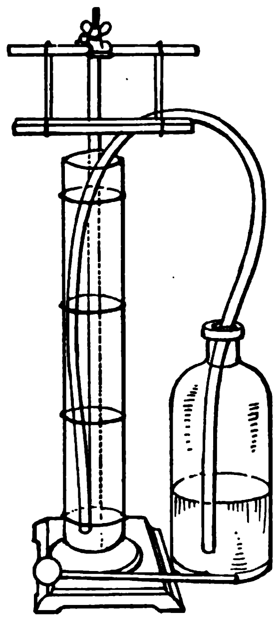
FREQUENCY OF VIBRATING BAR

Resonance. When sound waves are directed into a tube or pipe in which reflecting surfaces may be placed, the loudness of the sound is augmented when the distance between the mouth of the tube and any reflecting surfaces is equal to an odd number of quarter-wave lengths. Resonance occurs when the reflecting surface is $\frac{1}{4}$, $\frac{3}{4}$, $\frac{5}{4}$, $\frac{7}{4}$, and so on of a wave length measured from the open end of the pipe. Pipes of different diameters, however, give different results for the first quarter-wave length. While by adding .4 of the diameter of the pipe to the distance between its end and the first reflecting surface, the influence of the diameter may be taken into account, thereby making this corrected distance very nearly equal to a quarter-wave length, it is better to measure only the half-wave lengths between any two consecutive reflecting surfaces, as the "perturbation of the extremities" does not extend below the first reflecting surface.

Since the speed s of sound in air is $332 \frac{\text{m.}}{\text{sec.}}$ at 0°, and increases .6 m. per degree rise in temperature, the frequency n of a sounding body having the wave length l may be found from the relation:

$$n = \frac{s}{l}.$$

What to use. Stand with clamp holding a horizontal rod from which is hung by loops of string a steel (magnet) or brass bar. 2″ × 18″ hydrometer jar connected by a rubber tube siphon with a bottle or battery jar containing water. Tuning fork mallet (a rubber-tipped pencil will do). Thermometer. Meter stick. Slender rubber bands fitting tightly around the jar.



To find the frequency of a vibrating bar by means of a resonant air column.

What to do. (1) Fill the hydrometer jar with water and completely immerse the rubber tube in it. Pinch one end of the tube together and draw it out so as to make the siphon discharge the water into the bottle or battery jar. Throughout the experiment keep one end of the siphon under water in the jar and the other end under water in the bottle.

(2) Lift up the bottle until the hydrometer jar is nearly filled with water. Then tapping the bar frequently with the mallet so as to keep it in vibration, lower the bottle in such a way that the level of the water in the jar will sink slowly. Mark with rubber bands the positions of the water levels where resonance occurs, that is, where the sound seems loudest.

(3) Having thus roughly located the levels of water giving resonance throughout the entire length of the jar, proceed to find their positions with more accuracy by raising and lowering the water level rapidly in the vicinity of each rubber band. The sudden change in loudness will enable you to adjust the rubber bands with nicety at the levels where maximum resonance takes place.

(4) Measure to tenths of a centimeter the distances between the rubber bands, and double them to get the wave length of the tone. Note the temperature of the water.

(5) Compute the speed of sound in air at the temperature observed, and divide it by the average wave length; the quotient is the frequency.

TABULATION

	I	II
Temperature	°	°
Speed of sound at the observed temperature	m.	m.
Distance between the 1st and 2d resonance levels	cm.	cm.
" " " 2d and 3d " "	cm.	cm.
" " " 3d and 4th " "	cm.	cm.
Average distance between resonance levels	cm.	cm.
Wave length of the tone emitted by the bar	cm.	cm.
Frequency of the tone emitted by the bar		

EXPERIMENT XXXV

SPEED OF SOUND BY KUNDT'S METHOD

Principle of the Method. The relation between frequency n, wave length l, and speed s of a sound is $s = n\,l$. With tones of the same frequency but produced or transmitted in different media,

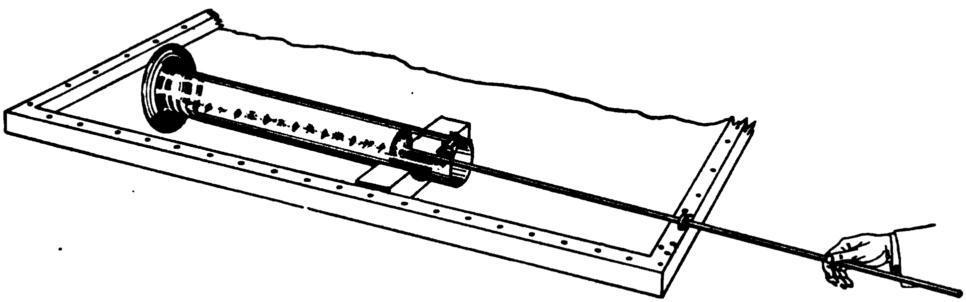
$$\frac{s}{l} = n = n' = \frac{s'}{l'} \text{ or, } \frac{s}{l} = \frac{s'}{l'};$$

where s, n, and l refer to air, and s', n', and l' refer to any other medium, such as brass or aluminum. If s is known, and l and l' are measured,

$$s' = s\frac{l'}{l}.$$

By rubbing a rod or tube clamped fast at its middle point lengthwise, it is set into *longitudinal vibration*. A node must be at the point clamped, and antinodes at the ends of the rod. The wave length of the tone due to the longitudinal vibration is therefore twice the length of the tube. The disk fastened to one end of the tube and placed within the jar moves to and fro, alternately compressing and rarefying the confined air. When, just as in the Experiment on Resonance, the distance from the vibrating body (disk) to a reflecting surface (bottom of the jar) is equal to any multiple of a quarter-wave length, resonance occurs and stationary waves are set up. When, by adjusting the distance between the vibrating body and the reflecting surface, such a state of affairs is obtained, the vibrating air bandies any light substance, such as cork dust, to and fro at its antinodal points but leaves it undisturbed at the nodal points. The air is forced to vibrate at the same rate as the rod; hence the frequency of the waves in both media is the same. The distance between similarly and consecutively placed cork ridges is half a wave length; that from the disk or from the bottom of the jar to the middle of the nearest cork ridges is a quarter-wave length.

What to use. Brass or aluminum rod or tube from 80 to 110 cm. long with a cardboard disk fastened on one end by sealing wax, and of such a diameter that it fits easily into a 2-in. × 18-in. hydrometer jar. General utility board with peg-and-collar clamp to fasten the tube. Thermometer. Cork dust prepared by rubbing a baked cork on a fine file or sandpaper. Rubbing cloth or leather. Rosin. Meter stick.



General Utility Board with Accessories for Kundt's Experiment

To find the speed of sound in . . . . by measuring the wave lengths of one and the same tone in the metal and in air.*

What to do. (1) Set up the apparatus as shown in the figure. The tube or rod is clamped securely at its middle point with the disk just within the mouth of the jar, in which a very little cork dust has been evenly sprinkled. Put books or other supports on either side of the jar to keep it from rolling.

(2) Rub the tube with the rosined cloth gently and steadily from near the middle

* Insert the name of the metal of which the tube or rod is made.

toward its free end. With a little practice you should be able to elicit a shrill, clear tone from the tube.

(3) Make the tube sound and note whether the cork dust is agitated. If not, move the hydrometer jar 2 or 3 mm. in such a way as to make the disk enter more into the jar. Again sound the tube and note the effect upon the cork dust. Continue moving the disk inward by small intervals, and when the dust begins to dance about, shorten (or lengthen) the distance between the disk and the bottom of the jar until the agitation of the dust becomes the most violent. It will then form similar groups of parallel ridges. Make the final adjustment by rotating the jar a little so as to carry the dust up on one side, and then sounding the tube. The dust between the nodes will slide down while the nodes themselves will be marked by peaks of dust extending up the sides of the jar.

(4) Take the temperature of the air near the apparatus.

(5) Measure to tenths of a centimeter the distance from the middle point of the group of parallel ridges nearest to the disk to the middle point of the similar group nearest to the bottom of the jar.

(6) Roll the jar over so as to destroy the parallel ridges. Repeat (3), (4), and (5) twice and average the results.

(7) Divide the average distance by the number of intervening cork ridges, and double the quotient to get the average wave length of the tone in air.

(8) Measure to tenths of centimeters the length of the tube and double it to get the wave length of the tone in the metal.

(9) Compute the speed of sound in the metal, taking the speed of sound in air as 332 $\frac{\text{m.}}{\text{sec.}}$, and its increase per degree Centigrade as .6 m.

TABULATION

Distance between groups	I	II	III
	cm.	cm.	cm.
	cm.	cm.	cm.
	cm.	cm.	cm.
Average	cm.	cm.	cm.
Wave length in air	cm.	cm.	cm.

	I	II	III
Length of ——* tube	cm.	cm.	cm.
Wave length in ——*	cm.	cm.	cm.
Temperature	°	°	°
Speed of sound in air at $t°$	m.	m.	m.
Speed of sound in ——* at $t°$	m.	m.	m.
Accepted value	m.	m.	m.
Per cent of error	%	%	%

* Insert the name of the substance composing the rod or tube.

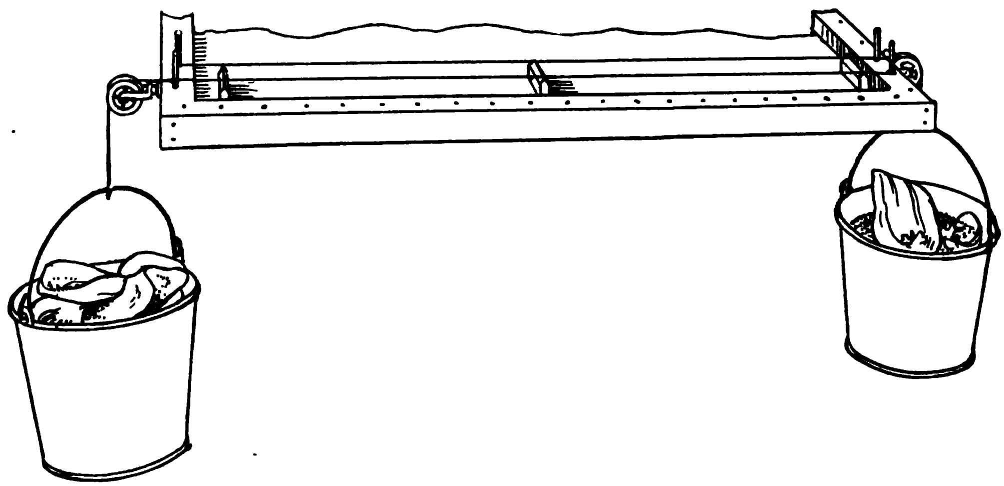
EXPERIMENT XXXVI

VIBRATING STRINGS — LAW OF LENGTHS

What to use. General utility board or sonometer* with two wires of the same size and material, such as steel wire with a diameter of about .3 mm. or spring brass wire with a diameter of about .5 mm. Three bridges. Two spring balances, tension keys or sets of weights with pulleys for adjusting the tensions of the strings. If the weights are placed in pails, a platform balance, steelyard, or large spring balance is needed.

To ascertain how the pitch of a tone emitted by a vibrating string varies with the length of the string.

What to do. (1) Stretch the wires over the general utility board or sonometer under such a tension as will make them when picked near the middle yield low and clear



General Utility Board with Accessories for Studying Law of Lengths

tones. Slip bridges underneath the wires near their extremities so as to make their vibrating portions of equal length, and adjust the tensions until the picked wires emit the same tone, *i.e.*, are in unison. Measure to millimeters the lengths of the wires.

How to Tell Unison. Even a slightly trained ear can usually decide whether two tones of the same quality have the same pitch or not. The sense of sight can help out the sense of hearing as follows: Put a tissue paper rider astride one wire and pick the other. If the two wires are in unison, or even nearly so, the unpicked wire will vibrate sympathetically with the picked wire, and the rider will be agitated and eventually thrown off.

The most delicate means of detecting slight differences in pitch is by means of beats. Rest the finger nails lightly upon the sounding board just after having set both wires in vibration. Any minute variation from unison will manifest itself as series of throbbings felt in the fingers, and ordinarily the ear can distinguish the regular increase and decrease in the loudness of the sound due to the beats. If the tones are both of strictly the same pitch, these throbbings cannot be felt nor the changes in loudness heard.

(2) Place a bridge under the middle point of one wire and pick both of its segments. How do the two tones compare in pitch (*a*) with each other; (*b*) with the tone of the other

* A mandolin has strings in pairs tuned to unison, and may be substituted for the sonometer. A guitar or other stringed instrument may be used if supplied with two strings of the same size and material.

wire. What is the musical interval between the tone produced by a vibrating wire and its tone when one-half as long? What is the ratio of the frequencies of the two tones constituting the musical interval? What relationship is there between the lengths of the wires and the frequencies of their tones?

(3) Move the bridge under one wire so as to divide it into two segments having lengths in the ratio of 8 to 1. Pick the longer segment and the unchanged wire in succession. What is the musical interval between the two tones? What is the ratio of the length of the longer wire to that of the longer segment?

(4) *Optional.* In similar fashion make the vibrating segments of one wire $\frac{8}{9}$ (.889), $\frac{4}{5}$ (.800), $\frac{3}{4}$ (.750), $\frac{2}{3}$ (.667), $\frac{3}{5}$ (.600), and $\frac{8}{15}$ (.533) as long as the other wire. What are the musical intervals for each adjustment?

TABULATION

Length of Unchanged Wire	cm.	Musical Interval	Ratio of Frequency of High Tone to That of Lower Tone Expressed as a	
Length of Shortened Wire	cm.	*Do* to ?	Decimal	Common Fraction

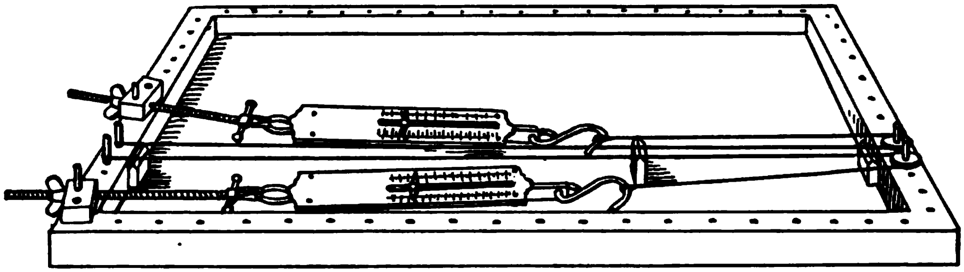
EXPERIMENT XXXVII

VIBRATING STRINGS — LAW OF TENSIONS

What to use. Two steel wires about .3 mm. thick stretched over the general utility board or a sonometer by means of 15 kg. spring balances, or weights with pulleys. Three bridges.

To ascertain how the pitch of a tone emitted by a vibrating string varies with the tension.

What to do. (1) Place bridges near the ends of the wires so as to make the lengths of their sounding portions equal. Stretch one wire with a force of 3 kg. Stretch the second wire with such a force that it will vibrate in unison with the first wire. How do the tensions compare? Measure the lengths of the wires.



General Utility Board with Accessories for Studying Law of Tensions

(2) Slip a bridge under one wire so as to divide it into two segments one of which is twice as long as the other. What is the ratio of (*a*) the length of the unchanged wire to that of the longer segment of the other wire; (*b*) the frequency of the longer segment to that of the unaltered wire? Pick the unchanged wire and the longer segment in succession. What is the musical interval of their tones?

(3) Increase the tension on the unaltered wire until it vibrates in unison with the longer segment of the other wire. Compare the ratio of the *squares* of the two lengths with the ratio of the tensions of the vibrating wires.

(4) Increase the tension on the wire of fixed length by 3 kg. and move the bridge under the other wire until both yield tones of the same pitch. Compare ratios as in (3). Make the tension on the wire of fixed length four times what it was at first. What is the musical interval between the tones? Move the bridge under the less tightly stretched wire until the tones produced by both wires are the same. Compare ratios as above.

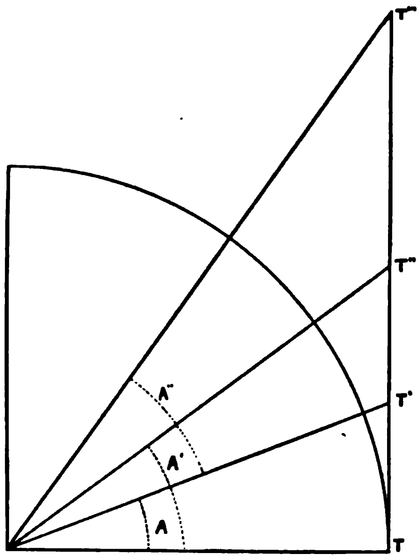
TABULATION

A Length of Wire *A* Under Varying Tension	*B* Length of Wire *B* Under Fixed Tension	*C* Tension of Wire *A*	*D* Tension of Wire *B*	A^2	B^2	$\frac{A^2}{B^2}$	$\frac{C}{D}$	$\frac{\text{Frequency of } A}{\text{Frequency of } B}$
cm.	cm.	kg.	3 kg.					
cm.	cm.	kg.	3 kg.					
etc.	etc.	etc.	etc.					

EXPERIMENT XXXVIII

REFLECTION OF LIGHT *

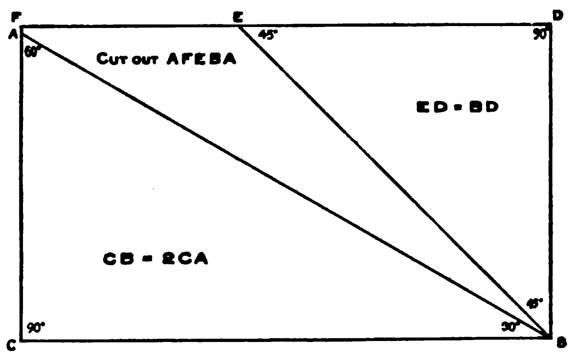
Definitions. A *ray* is the direction in which light travels, and is represented by a straight line. A bundle of parallel rays constitutes a *beam of light.* Rays that go towards or from a point (*focus*) form *converging* or *diverging pencils* of light, respectively. Any surface reflecting light regularly is a *mirror.* Mirrors are *plane, convex,* or *concave* according as their reflecting surfaces are *plane, convex,* or *concave.* A line perpendicular to a plane is the *normal* to that plane at a given point. A normal to a curved surface at any point is the perpendicular to the plane that is tangent to the curved surface at that point. The angle included by the normal to a mirror and an incident ray is called the *angle of incidence,* while the one between the normal and the reflected ray is the *angle of reflection.*



Tangent of an Angle. In the quadrant of the circle, let A, A', A'', etc., represent angles at the center, and let the radii forming their sides be extended until they intercept the geometrical tangent to the circle TT'''. While a geometrical tangent is indefinite in length, a trigonometrical tangent has a definite length. The trigonometrical tangents in the figure are as follows: tan A = TT', tan A' = TT'', tan A'' = TT'''. To compare the numerical values of trigonometrical tangents, the ratios of their lengths to the length of the radius are calculated. A Table of Tangents (see p. 173) shows how many times longer or shorter than the radius the tangent of a given angle is, or, since the radius forms the base of a right-angled triangle and the tangent its altitude, how many times longer or shorter than the base the altitude is.

What to use. Plane mirror.† Drawing board, general utility board, or a smooth table top of soft wood. Metric rule. Some pins.

* In Experiments XXXVIII, XXXIX and XL, geometrical diagrams are constructed from which general results are derived from measurements of the lengths of certain lines and the magnitudes of certain angles. The numerical values will not be reliable unless the diagrams are constructed with accuracy. The pencil used should be hard and must be kept well sharpened so that very fine lines may be drawn. The ruler must have a truly straight edge. A compass will be found convenient; one may be improvised by piercing two pinholes at the required distance apart through a strip of stout paper, a pin being inserted in one hole and a pencil point in the other. Protractors or draughtsman's triangles may be used for the construction of angles, but if they are not



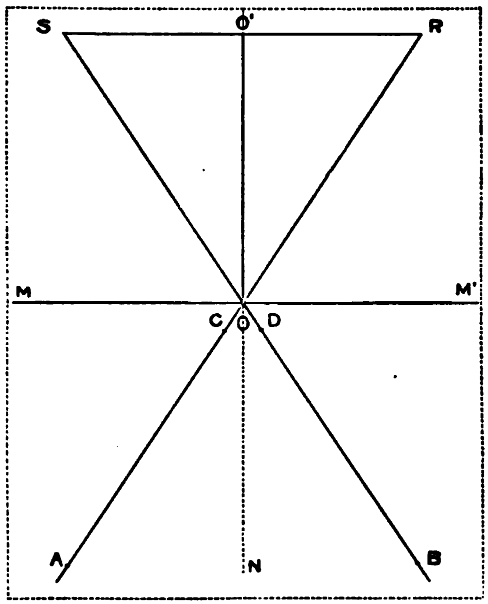
available, serviceable substitutes may be made as follows: Lay off on the short side of a postal card a distance AC equal to half the length of the card. Draw a line from A to B and cut the card along this line. A 30–60° triangle will be formed. A 45° triangle may be made by cutting a card in such a way as to form an isosceles triangle with its equal sides including an angle of 90° (the square corner).

† The mirrors may be strips of looking glass or of glass painted black on one side. The light is reflected from the back surface in the first case, and from the front surface in the second case. The mirrors are held in a

I. *To find relations between the angle of incidence and the angle of reflection of a ray of light.*

What to do. (1) Pin a sheet of paper smoothly on the board, and draw with a well-pointed hard pencil a straight line MM' across it at about its middle. Set the reflecting surface of the mirror vertically up on this line. About 10 cm. in front of the mirror stick two pins A and B vertically and about 12 cm. apart. With the eye almost in the plane of the paper, sight across it along the same sides of the pin A and the image of the pin B. Insert a third pin C near the mirror in line with A and the image of B. In like manner locate a pin D in line with the pin B and the image of the pin A.

(2) Remove the pins and the mirror, and draw fine lines through the pin pricks C and A, and D and B, respectively, prolonging them beyond the line MM'.



(3) Construct at the point O where CA and BD intersect MM', a perpendicular to MM' extending back of the mirror, and mark off on it a point O' near the edge of the paper. Through O' construct a perpendicular to OO' (parallel to MM'), cutting the prolongations of CO and DO in R and S, respectively. Construct the normal NO to MM'. Measure RO' and SO' to hundredths of a centimeter. How do their lengths compare? How then do the magnitudes of the angles ROO' and SOO' compare? The angle ROO' is equal to (Why?) the angle of incidence NOA for the ray of light coming from the pin A, while the angle SOO' is equal to the corresponding angle of reflection NOB.

(4) By trigonometry, $\tan ROO' = \frac{O'R}{OO'}$, and $\tan SOO' = \frac{O'S}{OO'}$. Measure OO', and calculate the tangents of the angles ROO' and of SOO' from the above equations.

vertical plane by fastening them to wooden blocks with rubber bands or strings. If made of thick plate glass, they will stand unsupported on edge.

Look up in the Table of Tangents (p. 173) the angles corresponding to the tangents calculated. How do their magnitudes compare?

(5) Repeat the foregoing work with the pins A and B in another position.

(6) Derive from your results *two* laws in regard to the reflection of light.

TABULATION

The construction with the measurements marked on the lines constitutes a good record in itself, but the following may also be used:

$R'O'$	SO'	OO'	tan SOO'	tan ROO'	Angle of Incidence	Angle of Reflection
cm.	cm.	cm.			°	°

II. *To ascertain the character and the position of an image in a plane mirror.*

(7) Draw a line MM' across the middle of a sheet of paper fastened to the board, and set the reflecting surface of the mirror upon it. Stick a pin A into the paper about 15 cm. in front of the mirror opposite its center.

(8) Sighting along the ruler laid on the extreme left of the paper with one of its ends near the mirror, adjust it until it is in line with the image of the pin, and draw a line along the ruler. Repeat with the ruler at the extreme right of the paper.

(9) Remove the mirror and continue the lines until they meet. How do you know that the position of the image is at the intersection O of these lines?

(10) Draw a line from A to O and put the letter D where the line AO crosses the line MM'. Using the square corner of a sheet of paper, see if the angles MDO and $M'DO$ are right angles. Measure AD and OD and compare their lengths. How does the distance of an object in front of a plane mirror compare with the distance of its image behind the mirror? Can you place a screen behind the mirror so as to catch upon it the image of the pin? What kind of image is given by a plane mirror?

(11) Make two more trials, one with the pin A near the right-hand edge of the paper, and the other with the pin near the left-hand edge.

III. *Optional. To ascertain the relation between the angular motion of a mirror and the angular motion of a ray of light reflected from it.*

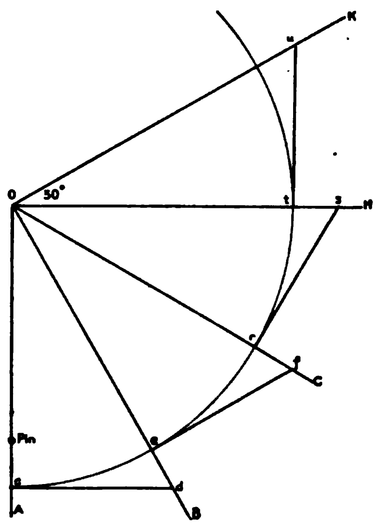
(12) Draw a line MM' across the middle of a sheet of paper on the board, and measure off on it from a point O near the left-hand edge a distance OT nearly to the right-hand edge. Erect at T a perpendicular TU equal to OT, and connect U with O. What is the value in degrees of the angle TOU? Draw on the opposite side of MM' the lines OA and OB perpendicular to MM' and OU, respectively. What are the values of the angles AOB and BOU?

(13) Set the reflecting surface of the mirror on MM' and stick a pin A in the line OA at least 15 cm. from the mirror. In the continuation of what line does the image of the pin appear? Move the mirror around so that its reflecting surface lies in the line OU. Through what angle has the mirror been rotated? Along the continuation of what line does the image now appear to be? What is the relation between the angular motions of the mirror and the reflected ray for this case?

(14) Place a fresh piece of paper on the board and construct an angle of 30° with its vertex near the left-hand edge and the middle of the paper, either by geometrical methods or by the aid of a protractor or a 30-60° triangle. Letter the sides *OH* and *OK*, and draw the perpendiculars *OA* and *OB*.

(15) Stick a pin in *OA* 15 to 20 cm. from *O*, and, placing the mirror on *OH*, note the direction of the image with respect to *AO*. Rotate the mirror around *O* through an angle of 30° so that it comes into the line *OK*. Sight along the ruler at the image of *A* and draw the line *OC*. While the mirror has rotated through the angle *KOH*, the reflected ray has rotated through the angle *AOC*.

(16) Remove the mirror and the pin, and, with as large a radius as possible, from *O* as a center, strike an arc extending from *OK* to *OA*. Erect at the points *c*, *e*, *r*, and



t the perpendiculars as shown. The lines *cd*, *ef*, *rs*, and *tu*, respectively, are the tangents of the angles at the center of the arc, and their lengths are proportional to these angles. Measure the lengths of these tangents and divide each length by the length of the radius. Find in the Table of Tangents the angles corresponding to the tangents as calculated from your measurements. Compare the magnitudes of the angles, and see if your conclusion from (13) is corroborated.

(17) Construct any other angle and find out in a way similar to the above if the relationship found in (13) is generally true.

EXPERIMENT XXXIX

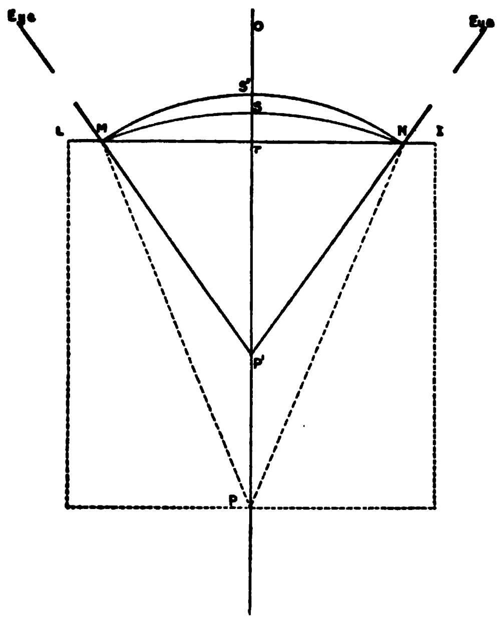
REFRACTION OF LIGHT

What to use. General utility or drawing board. Refraction plate. Metric rule. Some pins. Compass.

To find the ratio of the speeds of light in air and in glass; that is, to determine the index of refraction between glass and air.

I. WAVE METHOD

What to do. (1) Draw a line LI across the middle of a sheet of paper laid on the board, and make its length equal to that of the polished ends of the refraction plate. Construct a perpendicular OP at the middle point of LI, making rP equal to the distance between the polished ends. Insert pins at P, M, and N so that $rM = rN$.



(2) Lay the refraction plate flat on the paper in the position indicated by the dotted lines, forming a square with a polished end coincident with LI. With the eye almost in the plane of the paper and looking through the glass, insert a pin near the edge of the paper at $E(ye)$ in line with M and the image or apparent position of the pin P, as seen through the glass. In like manner locate a pin on the other side in line with N and the image of P.

(3) Remove the glass plate and the pins, and draw lines from E and E' through M and N, respectively, so that they intersect at P'. With P as a center and a radius equal to $PM = PN$, construct the arc MsN, and with P' as a center and a radius equal to $P'M = P'N$, construct the arc $Ms'M$.

(4) Measure to hundredths of a centimeter the length of PM and of $P'M$. The

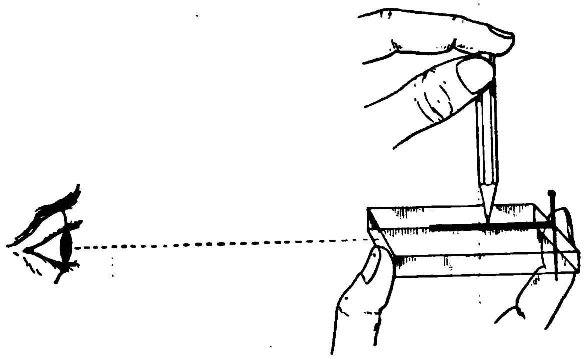
quotient of PM by $P'M$ gives the ratio of the speeds of light in air and in glass, or the index of refraction.*

(5) Repeat (2), (3), and (4) with the pins M and N in other positions but always so that $Mr = Nr$. Preserve the diagrams or accurate copies of them in your note-book, writing alongside the lines their respective lengths, and underneath the diagram the index of refraction as found.

II. Parallax Method

(6) Hold a pencil point upwards in the left hand at arm's length and a second pencil point downwards in the right hand at about three-fourths that distance. Close one eye and bring the points of the pencils in line with each other. Without moving the pencils look at their points with the other eye, closing the first; also shift the head to one side when viewing them with either eye closed. Move the pencil points closer together and see what effect viewing them with one eye at a time as well as moving the head to one side and the other has upon the distance they appear to be apart. Finally place the points in contact and note that in this position, no matter how viewed, the points do not appear to shift their relative positions.

This apparent change in the relative positions of two points when viewed from different places is called *parallax;* and the method just described of ascertaining which of two points is the farther, or whether they are equally distant, by altering the point of view, is known as the Method of Parallax.



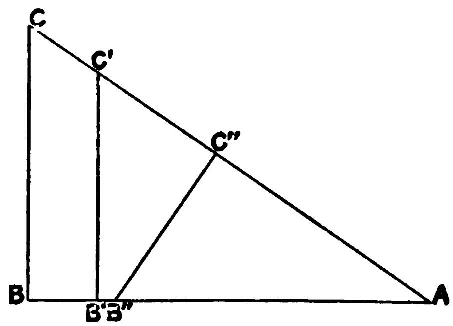
(7) Paste a narrow strip of paper about 5 cm. long on one surface of the refraction plate so that it extends between the polished edges. Hold the plate in the same plane with the eyes, and hold by one finger a pin against a polished end in line with the middle of the paper strip. Look through the glass at the pin, at the same time bringing a sharp pointed pencil down upon the paper. Adjust the position of the pencil until its point seems to touch the pin within the glass when viewed by either eye alone or when the head

* If it were possible for the eye to be within the glass, it would see the pin at the point P, just where it does see it in air when the plate is removed. P is the center of the light waves in either medium when the other is absent. But when the pin is viewed through both air and glass, the direction of the waves is changed abruptly at the surface between the two media. The curvature of the waves is likewise changed, the center of the waves after emerging from the glass being at P'. rs and rs' represent the amounts of curvature, that is, the amounts by which the curved lines depart from the straight line MrN. By definition, the curvatures of two arcs are inversely proportional to their radii. Hence the ratio of the two curvatures rs'/rs is equal to the ratio $PM/P'M$. The wave with P for a center travels as many times faster than the wave with P' for a center as rs' is times longer than rs, or PM is times longer than $P'M$.

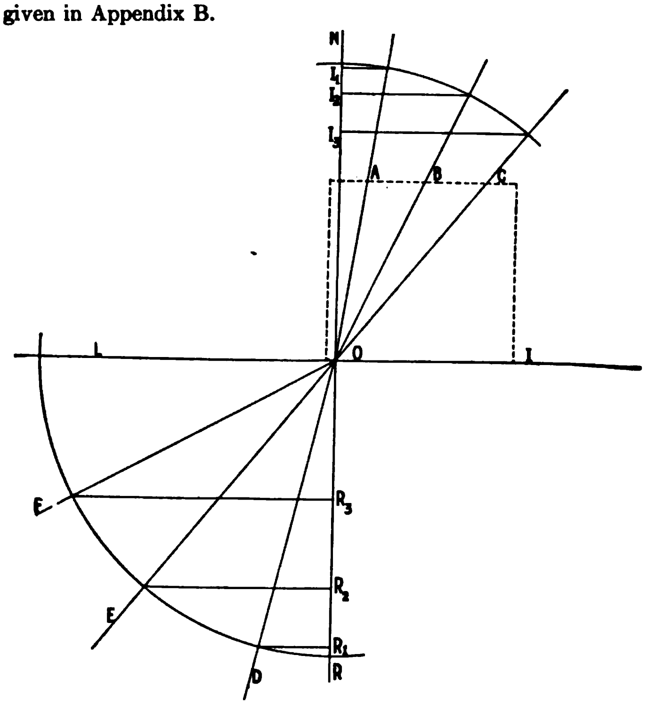
is shifted to one side or the other. Make a dot on the strip to mark the apparent position of the pin.

(8) Measure to hundredths of a centimeter the distance between the polished ends of the glass plate and the distance betweeen the dot on the paper and the front end of the plate. Divide the real width (the first distance) by the apparent width (the second distance); the quotient is the index of refraction. Compare the value thus obtained with that obtained by the wave method.

III. Sine Method



Sine of an Angle. In a right triangle the ratio of either of the sides including the right angle to the hypothenuse is called the sine of the angle opposite that side. In the triangle ABC the sine of the angle A is CB/AC, $C'B'/AC'$ or $C''B''/AB''$, and the sine of the angle C is AB/AC. While the sine of an angle increases as the angle increases from 0° to 90°, it does not increase proportionally. To compare the values of the sines of angles, the ratios of the opposite sides to the hypothenuse have been computed. A Table of Sines is given in Appendix B.



(9) Lay a sheet of paper on the board and draw through its middle point O two lines NR and LI at right angles to each other, the length and breadth, respectively,

of the paper. Lay the edge of a polished end of the refraction plate along the line LI as shown by the dotted lines. Stick pins at O, A, B, and C, touching the plate.

(10) With the eye almost in the plane of the paper, stick a pin D close to the front edge of the paper in line with the pin at O and the pin A, as it is seen through the glass. In like manner locate the pins E and F in line with O and the pins B and C, respectively.

(11) With as large a radius as possible strike arcs from O for a center like those shown in the figure. From the points of intersection of these arcs with the lines representing the incident and the refracted rays, construct perpendiculars to the line NR, and letter the perpendiculars constructed for the incident rays, I_1, I_2, and I_3, and those for the refracted rays, R_3, R_2, and R_1. Measure to hundredths of a centimeter the lengths of these sines thus constructed, and write their lengths beside them.

(12) Compute the ratios R_1/I_1, R_2/I_2, and R_3/I_3, and find their average. How does this average value for the ratio of the sine of the angle of refraction to the sine of the angle of incidence compare with the value of the index of refraction found by the two other methods?

TABULATION

I_1	I_2	I_3	R_1	R_2	R_3	R_1/I_1	R_2/I_2	R_3/I_3	Average Ratio
cm.	cm.	cm.	cm.	cm.	cm.				

Index of refraction found by Wave Method ....
Index of refraction found by Parallax Method ....
Index of refraction found by Sine Method ....

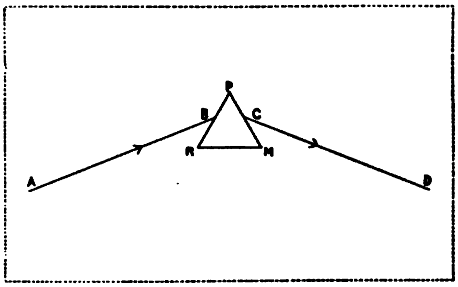
EXPERIMENT XL

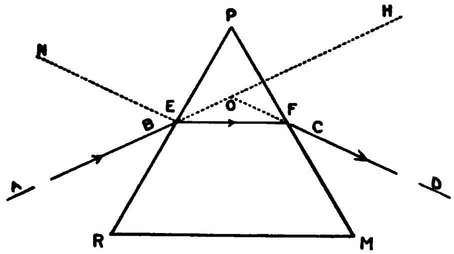
PRISMS

What to use. Equilateral prism. General utility or drawing board. Some pins. Ruler or straight edge.

To trace the path of a ray of light through a prism.

What to do. (1) Stand the prism on end upon a sheet of note-book paper fastened to the board and set up two pins A and B. The line AB marks the direction of a ray of light incident on the side PR of the prism. Look through the prism from the side





PM and adjust the position of the prsim until you can see the images of both A and B. Then set up two pins C and D (or sight along a straight edge) that seem to be in the same straight line with B and A.

(2) Trace the outline of the prism, and remove it and the pins. Draw lines through the pin pricks up to the lines marking the positions of the edges of the prism, and draw the line EF showing the direction of the ray through the prism. The angle DOH is called the *angle of deviation.*

(3) Repeat (1) and (2) twice with different angles of incidence. Does the angle of deviation seem to have its greatest or its least value when the angle of incidence is nearest equal to the angle of reflection, that is, when EF is parallel to RM?

EXPERIMENT XLI

CONCAVE MIRRORS

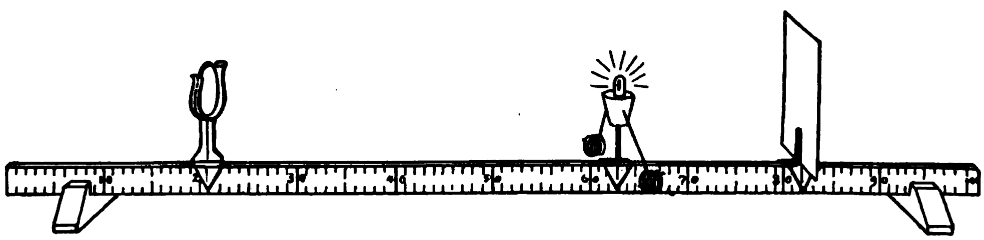
What to use. Optical bench consisting of a meter stick upon which slide supports for holding the following objects: screen, mirror, illuminated object such as a knitting or darning needle end, luminous object such as a candle flame, a small gas flame, or a small incandescent lamp lighted by a battery or other source of current.

I. *To find the principal focal length of a concave mirror.*

What to do. (1) Attach a screen made of a paper or cardboard strip about 1 cm. ×10 cm. to a support in such a way that it is opposite the middle of a concave mirror similarly supported. A narrow screen is used because it will cut off but little light from the mirror.

(2) Reflect sunshine from the mirror upon the screen, and adjust the distance between them to make the image of the sun as small as possible. Measure to tenths of a centimeter the distance between the screen and the surface of the mirror. Make three such adjustments and measurements. The sun is so far from the mirror that its rays are practically parallel; the average of the distances measured is therefore the focal length of the mirror.

(3) Reflect the image of some brightly illuminated object, such as a house or tree, at least 250 ft. away, upon the screen, and adjust the position of the screen until the outlines of the object are rendered very distinct. Make three such adjustments, and measure for each the distance between the mirror and the screen. How does the average focal length obtained by the sun method compare with the average focal length obtained by the distant object method?



II. *To study the characteristics of an image formed by a concave mirror.*

(4) Place the needle as close to the mirror as possible. Is the image real or virtual? Move the needle slowly away from the mirror, and note how its size changes. At about what distance from the mirror do the outlines of the image become very indistinct, and about where does the image become inverted? When the needle is beyond this point, is it real or virtual? Move the needle gradually as far as possible from the mirror, and note how the size of the image changes.

III. *To measure the radius of curvature of a concave mirror.*

(5) Place the mounted needle on the optical bench with its point opposite the center of the mounted mirror, and move it out to about twice the focal length from the mirror. Shift the needle support until the image of the point coincides with the point itself, employing the Method of Parallax. (See Experiment XXXIX, Part II.) If the relative

positions of the needle and its image remain the same even when the head is moved from side to side in such a way as to change the point of view, both image and point are at the same distance from the mirror, and this distance is equal to the radius of curvature. Make three independent adjustments and measurements. How does the average radius of curvature compare with the average focal length?

(6) (A dark room is required, or, at least, the laboratory must be darkened as much as possible by drawing the shades.) Place the luminous object about halfway between the principal focus and the center of curvature, and move a large screen to and fro beyond the center of curvature until a sharply defined image is seen. Is this image real or virtual; erect or inverted? How does its size compare with the size of the object? Measure the distance between the object and the mirror (object-distance u) as well as between the image and the mirror (image-distance v). How does the sum of the reciprocals * of these distances compare with the reciprocal of the focal length?

(7) Repeat (6) with the luminous object a couple of centimeters nearer to the mirror, and also a couple of centimeters farther away from the mirror.

(8) Place the luminous object beyond the center of curvature, and a narrow screen between the center of curvature and the principal focus. Make adjustments and observations similar to those of (6) and (7).

TABULATION

Principal focal length f by the sun method	cm.
	cm.
	cm.
Average........	cm.
Principal focal length f by the distant object method	cm.
	cm.
	cm.
Average........	cm.
Radius of curvature r	cm.
	cm.
	cm.
Average........	cm.

RELATION OF DISTANCES — CHARACTERISTICS OF IMAGES

				Kind (real or virtual)	Position (erect or inverted)	Size (larger or smaller than the object)	Location † (with respect to f, r, and mirror m)
When the object is at an infinite distance, the image is							
When the object is between the mirror and the principal focus, the image is							
Object-Distance u	Image-Distance v	$\frac{1}{u}+\frac{1}{v}$	$\frac{1}{f}$				
cm.	cm.						
cm.	cm.						
cm.	cm.						
cm.	cm.						

* The reciprocal of a number is one divided by that number.

† State whether the image is between the principal focus f and the center of curvature c, between f and the mirror m, or beyond the center of curvature.

EXPERIMENT XLII

CONVEX LENSES

What to use. Double convex lens having a focal length of from 7 cm. to 10 cm. Optical bench with supports for the lens, a needle, a translucent screen (ground glass or translucent paper or cloth) and an opaque screen (cardboard). Sheet-iron cylinder with an L-shaped opening in it. Luminous gas flame, or Bunsen burner with a bit of asbestos paper, previously soaked in salt solution, wrapped around the end. The salt volatilizes and colors the Bunsen flame yellow (monochromatic light). Metric rule. (For the optional part a reading glass is needed.) Stand with clamp.

I. *To locate the principal focus of a converging lens, and to measure its focal length.*

What to do. (1) Mount the lens and the translucent screen on the meter stick, and point the optical bench toward the sun so that its rays will be parallel to the meter stick. Move the screen back and forth until a position is found where the image of the sun formed by the lens and caught on the screen is smallest and brightest. Measure to tenths of a centimeter the distance between the edge of the lens and the side of the screen nearer the lens. Since the sun's rays are practically parallel, this distance is the principal focal length. Make three such measurements and compute their average.

(2) Draw the window shade nearly down, open the window and point the optical bench toward some distant object that is well illuminated, such as a tree or a chimney against a clear sky. Adjust the screen and the lens until a well-defined image of the object is obtained on the screen. A hood of opaque paper bent into a ∧-shape and laid over the lens and the screen will cut off side light so that the image will appear brighter; telescoping tubes made of two rolls of opaque paper or of two mailing tubes will answer the same purpose. Measure the distance between the edge of the lens and the screen; it is equal to the focal length. Repeat this operation twice and take the average of the measurements.

II. *To study the characteristics of images formed by a convex lens.*

(3) Place the mounted lens 25 cm. from the end of the meter stick and bring the mounted needle as close as possible to the farther face of the lens. Holding the end of the meter stick close to your face so that the lens is 25 cm. from the eyes, move the needle slowly away from the lens. What change is there in the size of the virtual image as the object recedes from the lens? Which increases the more rapidly, the distance of the image or the distance of the object from the lens?

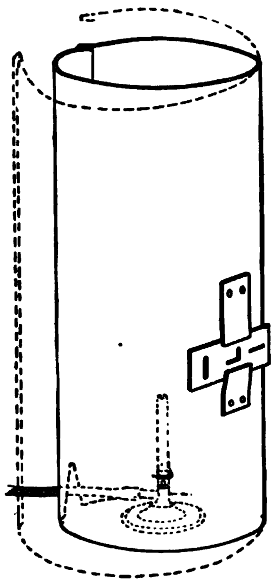
(4) Move the needle slowly away from the lens until the outlines of the image just begin to grow indistinct. Measure the distance where this takes place, making three trials and taking their average. How does this determination of the focal length by the " virtual image method " compare with the values obtained by the other two methods?

(5) *Optional.* Repeat (1) (or (2), and (3) and (4) with a reading glass, not using, however, the optical bench, but simply holding the glass in the hand. It is unnecessary to try to get very accurate results. Since a virtual image formed by a converging lens can be seen only when we look through it at an object, is it the magnified object or its

magnified virtual image that we see through a reading glass? Read some print through the glass, keeping the eyes 25 cm. from the print and holding the lens at various intermediate distances. Why is a reading glass large and why is its focal length about 25 cm.?

III. *To find the relation* (a) *between the focal length of a lens and its conjugate focal distance, and* (b) *between the size of the object and the image and their respective distances from the lens.*

(6) Light the gas (or turn on the electricity) and put the sheet-iron cylinder over the burner. Place the mounted lens in front of the L-shaped opening at a distance equal to twice its focal length, supporting the meter stick, if needs be, in the clamp of the stand so as to bring the L and the lens on the same level. With the room darkened as much as possible, adjust the screen so that a sharply defined image of the L is caught



upon it. What are the characteristics of this image? Measure to tenths of a centimeter the distance from the edge of the lens (*a*) to the L-shaped opening (denote this object-distance by u); (*b*) to the screen (denote this image-distance by v). How does the image-distance compare with the object-distance? Measure to hundredths of a centimeter the lengths of the two slits constituting the L (dividers are handy for this purpose). Add these two lengths and call their sum the object-size. In similar fashion find the image-size. How does the image-size compare with the object-size?

(7) Place the screen between four and five focal lengths from the L, and move the lens as near to the L as possible in order to get a well-defined image on the screen. Measure as in (6) the image-size, the image-distance, and the object-distance. How does the ratio of the image-distance to the object-distance compare with the ratio of the image-size to the object-size?

(8) Keeping the screen at the same distance from the L as in (7), move the lens toward the screen until a good image is obtained. Measure and compare as in (7).

(9) *Optional.* Repeat (7) and (8) with the screen still farther from the L-shaped opening.

(10) Compute f, the focal length, from the lens formula: $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$, which, solved for f, gives

$$f=\frac{uv}{u+v}$$

How does the average of the focal lengths obtained by this conjugate foci method compare with the average values found by the other methods?

TABULATION

FOCAL LENGTHS

Sun Method	Distant Object Method	Virtual Image Method
cm.	cm.	cm.
cm.	cm.	cm.
cm.	cm.	cm.
Av. cm.	Av. cm.	Av. cm.

u	v	$\frac{uv}{u+v}=f$	Object-Size	Image-Size	u/v	Image-Size/Object-Size
cm.	cm.	cm.	cm.	cm.		
cm.	cm.	cm.	cm.	cm.		
cm.	cm.	cm.	cm.	cm.		
		Av. cm.				

EXPERIMENT XLIII

THE SIMPLE MICROSCOPE

To find the magnifying power of a simple microscope.

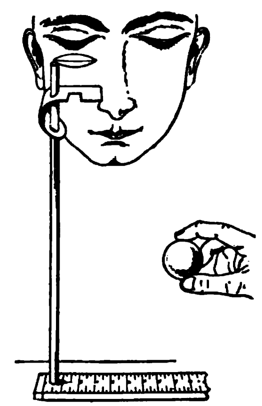
What to use. Bi-convex lens of 7 cm. to 10 cm. focal length. Slender stick or stiff wire 25 cm. long. Piece of black cardboard cut as shown in the figure. Metric rule.

What to do. (1) Determine the focal length of the lens by one of the methods of Experiment XLII.

(2) Slip the stick through the slits of the cardboard and bend the board at right angles. Adjust the slit, which should be about one centimeter wide, until it is at the focal distance of the lens from one end of the stick.

(3) Hold the lens at one end of the stick at its focal distance from the cardboard, and with the stick held vertically set its other end on a metric rule laid upon the table. Bring one eye as close as possible to the lens and look through it at the slit in the cardboard, while the other eye is viewing the metric rule 25 cm. away, the least distance of distinct vision. Winking the eyes helps to see both the slit and the scale clearly at the same time. Note how many millimeters on the scale come between the sides of the slit. Measure to hundredths of a centimeter the width of the slit.

(4) One eye sees the *magnified* slit in the cardboard, while the other eye sees the *unmagnified* scale at the distance of distinct vision. The ratio of the magnified width of the slit to its actual width is the magnification produced by the lens, or its magnifying power. The magnifying power may also be found by dividing 25 by the focal length of the lens. Compute the magnifications as found by both methods, and find their per cent of difference.



TO AVOID CONFUSING THE DETAILS OF THE FIGURE, THE HAND HOLDING THE LENS IS SHOWN SEPARATELY AT THE RIGHT; THE BLACK DOT ON THE LENS REPRESENTS THE END OF THE STICK

TABULATION

A	Focal length of the lens	cm.
B	Actual width of the slit	cm.
C	Magnified width of the slit	cm.
	Magnification C/B	diameters
	Magnification $25/A$	diameters
	Per cent of difference	%

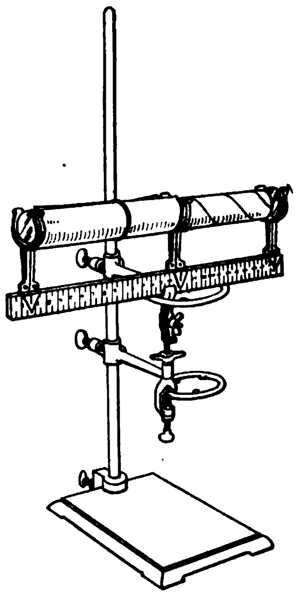
EXPERIMENT XLIV

ASTRONOMICAL TELESCOPE

What to use. Two double convex lenses, one having a focal length of from 7 cm. to 10 cm., and the other of about 25 cm. Meter stick. Optical bench with supports for the lenses and for a screen (preferably of ground glass or of translucent paper or cloth). Clamp and stand. Hood of opaque paper about 20 cm. x 40 cm. bent lengthwise into a ∧-shape, or an opaque (mailing) tube mounted on a support and provided with a telescoping tube of pasteboard or paper held in place by rubber bands.

To combine two converging lenses so as to form a telescope, and to measure its magnifying power.

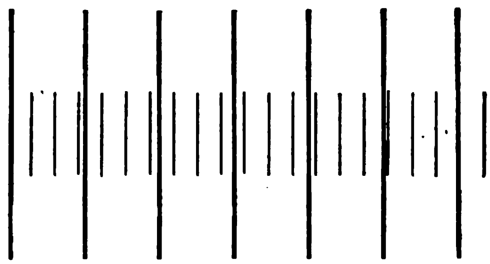
What to do. (1) Find the focal lengths (if not already determined) of the lenses by the sun or the distant object method. Lay the hood over the mounted lens (or interpose the tube) and screen so as to cut off the side light, and thereby get a brighter image. Call the lens with the smaller focal length f_1 the eye piece, and the lens with the greater focal length f_2 the objective.



AN IMPROVISED TELESCOPE

(2) Mount the eye piece at one end of the meter stick and the objective at a distance from it about equal to the sum of the focal lengths of the lenses. Support the meter stick in the clamp of the stand at a convenient height, and point the telescope thus formed at some well illuminated object, such as a chimney or a tree. Applying one eye close to the eye piece, adjust the objective until the outlines of the image are as distinct as you can make them. The image will be more clearly seen if the hood be placed over (or the tube be placed between) and against the lenses. To what are the colored fringes of the image due? Measure the distance l between the edges of the lenses. Make three trials, viewing a different object each time. How do l and $f_1, + f_2$ compare?

(3) Mark several equidistant (about 5 cm.) and horizontal lines on the blackboard, or draw them on a piece of cardboard hung upon the wall at the same height as the telescope. View these lines through the telescope, adjusting the focus and cutting off the side light by means of the hood (or the tube). While looking through the telescope at the lines with one eye, view them with the other eye along a line of sight by the side of the telescope. Do not strain the eyes, but try to look naturally at both image and object. Winking aids in seeing clearly the image and the object at the same time. Estimate how many lines of the object are included between two lines of the image. Make three trials with different lines each time.



(4) The magnifying power of a telescope is equal to (*a*) the ratio of the size of the image to that of the object; (*b*) the ratio of the focal length of the objective to that of the eye piece. How do the values of the magnifying power measured by the two methods compare?

TABULATION

f_1	f_2	$f_1 + f_2$	l	f_2/f_1	$\frac{\text{Image-Size}}{\text{Object-Size}}$
cm.	cm.	cm.	cm.		
cm.	cm.	cm.	cm.		
cm.	cm.	cm.	cm.		
Av.					

EXPERIMENT XLV

COLOR BY REFLECTION

What to use. Color top (an electrical one is preferable). Thin glass plate about 8 cm. × 10 cm. (a lantern slide cover glass is excellent). Piece of black cardboard or cloth about 10 cm. × 10 cm.

To find out what color results from the union of reflected colors.

What to do. (1) Fasten a black and a white disk to the top, leaving about three-fourths of the white disk exposed. Spin the top slowly and note the flickering appearance of the disks. Spin the top rapidly and note that the flickering almost disappears and that the disks take on a uniform dirty white color.

(2) Adjust the disks so that only about half of the white disk is exposed. The gray color observed on spinning the top is due to the fact that only about half as much light is reflected as would be reflected by the whole of the white disk. The black disk reflects practically no light at all, so that the gray color observed is a shade of white, that is, it is a white with but little light-reflecting power.

Expose only about one-fourth of the white disk and note that the color of the rotating disk is that of slate, a darker shade of white.

(3) Lay a white disk upon the black cardboard, and, holding a glass plate vertically on its edge close to the disk, look at the image of the disk. Here again the gray color observed is due to the lack of luminosity. Incline the plate from and then towards you and note the varying shades of white that the image presents.

(4) Fasten a blue and a yellow disk to the top so as to leave half of each exposed. Spin the top and note the color produced. If it is a shade of white like any of those obtained by the union of black and white, the two colors are said to be complementary.

(5) Lay the small blue and yellow disks near each other on the black cardboard and view the image of one of the disks, say the blue, through an interposed glass plate. Incline the plate towards you so that the reflected blue color will be stronger and stronger, and note the resultant color of the yellow disk as seen through the image of the blue disk. What evidence is there that the two colors are complementary? Exchange the positions of the disks and note the resultant color.

(6) Try all the different pairs of colors provided, both with the top and with the glass plate. When the resulting color is not a shade of white, vary the relative amounts of color in order to see if a white shade is obtainable. This may be done with the top by adjusting the proportion of the surfaces exposed, and with the glass plate by varying the angle that it makes with the cardboard.

TABULATION

Component Colors	Resulting Color
Blue and yellow	Gray
etc.	etc.

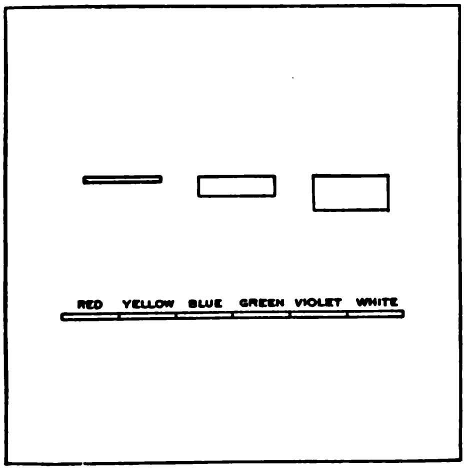
(7) *Optional.* Mark two faint pencil dots about 10 cm. apart on a piece of white paper. Place the center of the large red disk over one of the dots. Look intently at the disk for at least 30 sec. and then immediately look at the other dot. What color appears

in a few moments around this dot? The nerves of the eye that are affected by one color, say red, become fatigued, so that, when the gaze is transferred to a white surface, the reflected red in the white fails to stimulate those nerves, with the result that only the complementary color of the red is seen. Find the complementary colors of the other disks by this "retinal fatigue method."

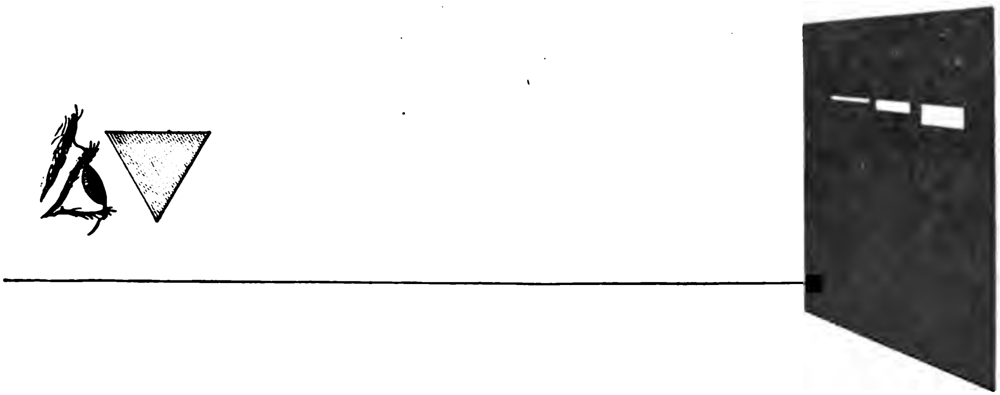
EXPERIMENT XLVI

SPECTRA

What to use. Equilateral prism. Piece of black cardboard about 12 cm. square. Three slits are cut in this cardboard, all of the same length — about 3 cm., but of the following widths — 1 mm., 5 mm., and 10 mm. Strips of colored papers about 1 mm.



x 10 mm. are pasted in a straight row so as to form a continuous band near the middle of one side of the cardboard or on a separate cardboard without the slits; the colors should include red, yellow, green, blue, and violet, and white. Darning needle. Screen of sheet iron with a slit about 1 mm. x 20 mm. Bunsen burner. Blotting paper. Dilute solutions of sodium chloride (common salt), lithium chloride, and thallium sulphate



Concentrated solutions of copper sulphate and potassium dichromate contained in small test tubes or homœopathic vials. Pieces of colored glass or gelatine about 5 cm. square; the colors should include red, yellow, and blue, and the shades of the yellow and the blue should be such as will give green when they are combined.

I. *To analyze, by means of a prism, direct, transmitted, and reflected sunlight.*

What to do. (1) Hold the cardboard in sunlight at arm's length about on a level

with the eyes with the slits horizontal. Holding the prism close to one eye with one of its faces horizontal, direct the gaze upward through the prism, rotating it slightly until the brightly illuminated slits are seen with the clear sky as background. Record in order the colors of the sun's spectrum as seen. Which color is refracted most, that is, which is farthest from the refracting angle of the prism? Why is it that the middle of the wider slits is white? What is the condition for obtaining a pure spectrum, that is, one in which the colors do not overlap?

(2) Cover half of the narrow slit with a piece of blue glass, and look at the slit through the prism. The spectrum of the light transmitted is now seen side by side with the spectrum of the sun. Record in the form shown in the figure, writing beside the names of the colors such words as bright, faint, etc., to indicate their relative prominence.

Red
Orange
Yellow
Green
Blue
Violet

(3) Repeat (2) with the other pieces of colored glass or gelatine; also with two pieces of glass or gelatine of different colors laid upon each other.

(4) Fill the small test tubes about a third full of copper sulphate and with potassium dichromate solutions, respectively, and find their absorption spectrum as above.

(5) Without using the prism, look at a sheet of white paper through the blue and yellow glasses placed together. Compare the absorption spectra produced by the two glasses separately, and account for the color now observed. Mix in a test tube a few drops of copper sulphate solution with a few drops of potassium dichromate solution. What is the change of color? See if you can prepare a mixture that has a color similar to that obtained by passing sunlight through both blue and yellow glass. Examine and record the absorption spectra of this mixture.

(5) With your back to the window, hold the cardboard in the same relative position as in (1) but with the band of colored papers illuminated by direct sunlight. With the prism held as in (1) view the strips of colored paper reflecting the sunlight to your eye. Does each one of these papers reflect only a single spectral color or several? Which of the papers give a nearly pure spectral color? Record what colors are and what colors

are not absorbed, adding a heading that gives the color of the strip. Such colors as are faint, distinct, prominent, etc., should be designated accordingly.

(6) *Optional.* Lay a bright darning needle across a couple of pencils upon a piece of black paper or cloth where it will be in sunshine. With your back to the sun, look through the prism at the needle and plot the spectrum of the reflected light.

II. *To study the spectra of incandescent solids and vapors.*

(7) View through a prism in a darkened room the light emitted by an incandescent lamp. (Its filament is made of carbon and is heated to incandescence by the current of electricity. A carbon spectrum can also be obtained by observing the spark on the end of a match stick or a strip of blotting paper kept bright by blowing upon it.) Compare the spectrum of carbon with that of sunlight.

(8) Examine the spectrum of a luminous Bunsen flame placed behind the iron screen, holding the prism parallel to the slit. How does it compare with that observed in (7)? What evidence that the luminosity of the flame is due to incandescent carbon does this observation present? Are there any colors faint or lacking in the spectrum of a gas flame?

(9) Examine the spectrum of the non-luminous Bunsen flame and record it.

(10) Let one student moisten thoroughly a strip of blotting paper in the sodium chloride solution, and then hold its tip in the bottom of the non-luminous flame, being careful not to let the paper catch fire. Some of the sodium chloride is carried up into the flame, where it is vaporized and its vapor heated to incandescence. Let another student (or other students) view the slit through a prism. Record the spectrum, the brightest color in which is due to sodium vapor. Bear in mind that you are seeing the spectrum of the non-luminous flame as well as that of the sodium. Leave out of your record the former spectrum as observed in (9).

(11) Repeat (10) with lithium chloride and such other solutions as are provided for the purpose, recording the bright-line spectrum of each.

(12) *Optional.* Let one student introduce into the flame any one or any combinations of the substances tested, and let another student, not knowing which substance is being used, try to detect it by an examination of its spectrum. Such a method of testing substances is known as *spectrum analysis.*

EXPERIMENT XLVII

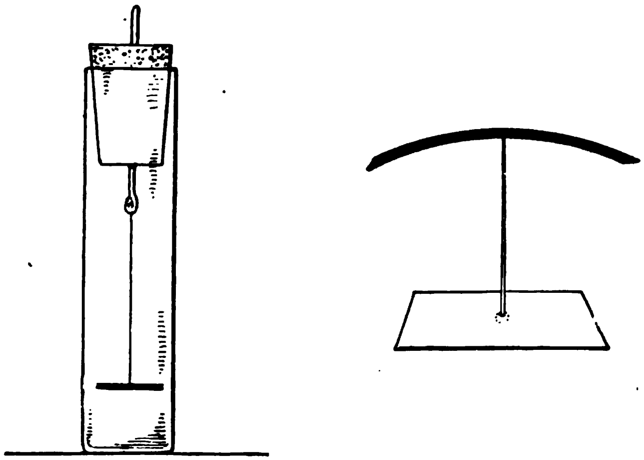
INTERACTIONS OF MAGNETS

What to use. Bar magnet. Watch spring. Tinner's snips or wire cutters. Magnetoscope. Iron filings.* Sheets about 10 cm. square of iron, copper, lead, zinc, glass, cardboard, and any other convenient substance. Tumbler of water on which floats a large cork disk.

Magnetoscopes. Any magnetized body free to turn in a horizontal plane around a vertical axis forms a magnetoscope. If the magnet is in the form of a flat piece of steel with pointed ends and mounted on a pivot over a graduated circle, the arrangement is called a compass. Magnetoscopes may be made as follows:

(*a*) Float a magnetized sewing needle or bit of watch spring directly upon water or upon a flat cork in water.

(*b*) Tie a fine silk thread or, better, a single silk fiber around the middle of a magnetic needle, putting a drop of shellac or of wax on the knot to prevent its slipping. Attach the other end of the silk to a hooked piece of wire passing through a cork in a bottle or homœopathic vial and make the needle horizontal, if needs be, by attaching a bit of beeswax to the higher end. Side motion can be largely prevented by having the suspension pass through a fine glass tube.



(*c*) With a sharp-pointed center punch make a dent in the middle of a piece of magnetized watch spring laid upon a flat stone or ingot of Babbitt metal, and bend down the ends a little. Or, the temper of the watch spring may be drawn by heating it to redness in a Bunsen flame, letting it cool slowly and then making the dent. The temper is restored by heating the steel to redness and dropping it immediately into cold water. A piece of steel rod about two millimeters in diameter or a steel pen may be used instead of the watch spring. Balance this magnetic needle on the point of a pin thrust up through a small square of pasteboard, using a pellet of wax to make it horizontal, if necessary.

To study the actions of magnets upon one another.

What to do. (1) Straighten out a watch spring and cut off a piece 5 to 8 cm. long, cutting one end on the bias so as to distinguish it from the square-cut end. Holding one end lightly between the thumb and finger, touch the other end to at least a dozen different substances, such as brass (screw, gas-pipe fitting), silver, nickel, bronze, gold (coins or jewelry), iron (screw or nail), paper, glass, etc., etc., and note which substances the

* Iron filings are best kept in a wide-mouthed bottle with a piece of cheese-cloth tied over its mouth, or in a kitchen salt shaker. They may then be sifted out in such amount as needed.

steel watch spring has a tendency, if any, to cling to. Holding the bar magnet nearly vertical, rub one end of it along the watch spring laid upon the table from one extremity to the other several times, always in the same direction. Then test the same articles as before. Which substances does the watch spring now tend to cling to?

(2) Place a little heap of iron filings on one of the sheets and move it over one end of the bar magnet held in a vertical position. Test all the sheets in this way. Which materials screen the iron filings from the action of the magnet?

(3) Lay the watch spring magnet made in (1) on a piece of smooth paper and sprinkle iron filing over it. Lift it up and note where the iron filings cling most thickly. At about the centers of the tufts of filings are located the *magnetic poles*, and the line joining them is the *magnetic axis*.

(4) Remove the iron filings from the watch spring magnet and lay it across the cork disk floating in the tumbler of water.* Note which end (the square-cut or the bias-cut) points northward. The pole of a magnet free to turn around a vertical axis that points toward the north is called the *marked*, *positive* (+), *north-seeking* or *N-pole*; that which points toward the south, the *unmarked*, *negative* (−), *south-seeking*, or *S-pole*.

(5) From a distance of at least ten centimeters bring one pole of the watch spring magnet held horizontally in a north and south line toward the south-seeking pole of a magnetoscope, and note the effect. Reverse the position of the watch spring magnet and repeat. Arrange your results as follows:

Pole of Magnetoscope	Pole of Magnet	Effect
North-seeking	North-seeking	?
North-seeking	South-seeking	?
South-seeking	South-seeking	?
South-seeking	North-seeking	?

Derive from your results a law for the action between magnetic poles.

* To prevent the cork from floating to the sides of the tumbler and sticking there, fill the tumbler full to overflowing, in such a way that the surface of the water is slightly above the rim of the vessel. The cork will then float to the middle of the surface of the water.

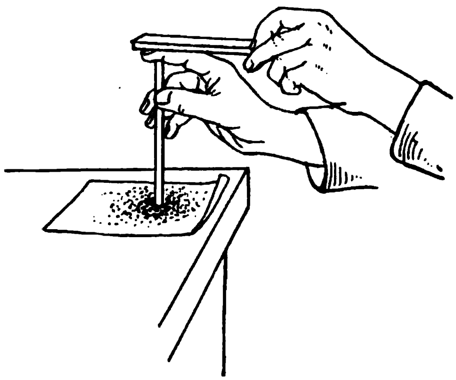
EXPERIMENT XLVIII

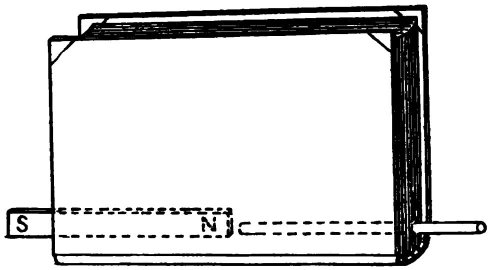
MAGNETIC INDUCTION

What to use. Bar magnet. Soft iron rod about 15 cm. long.* Watch spring. Iron filings. Magnetoscope or compass. Bunsen burner. Tumbler of water. Ring stand or crucible tongs. 4-in. test or ignition tube.†

To study the phenomena of magnetic induction.

What to do. (1) Dip either end of the iron rod into iron filings and note the amount, if any, that adheres to it.‡ Holding the rod vertically, with one end in the filings and the other end covered with the forefinger, put one pole of the bar magnet on that finger and lift up the rod with the magnet still resting upon the finger. Note the amount of filings now clinging to it. Remove the magnet and note what occurs. The soft iron retains its magnetic quality only when near a magnet. It forms a temporary magnet in contradistinction to permanent magnets which are made of steel. The permanent magret is said to induce magnetization in the temporary magnet.





(2) Place a bar magnet within a book close to its binding in such a way that by closing the book on the magnet it may be held firmly. Place the iron rod also between the same pages in the book in such a way that its end is very close to but not touching the end of the magnet. Bring the projecting ends of both magnet and rod in succession up to a magnetoscope and test their polarity. Reverse the magnet and repeat the tests. Reverse the rod and repeat. What are the relative positions of the poles of inducing and of induced magnets?

(3) Magnetize a piece of watch spring by rubbing it from the square-cut end to the bias-cut end with the south-seeking pole of a bar magnet. Test the polarity of the watch spring with a magnetoscope. What pole is induced in the bias-cut end? Rub the same watch spring at least a dozen times with the south-seeking pole of the bar

* So-called Norway iron is best. Wire nails are made of steel and do not usually give good results. Clout nails, however, are good. Stovepipe wire straightened and cut into equal lengths, when bound into bundles or crowded into glass or red fiber tubes, is excellent.

† As test tubes are very fragile, it is better to use ignition tubes or stout glass tubing cut into 4-in. lengths, with the ends closed with corks cut off flush with the surface of the glass.

‡ Results will not be definite unless the iron refuses to retain any appreciable amount of magnetism. If the rod takes up more than one or two filings when stirred around in them, it should be rejected and another one tried.

magnet from the bias-cut to the square-cut end and again test its polarity. Repeat the above two operations with the north-seeking pole of the bar magnet. What pole is induced in the end of the watch spring that the north-seeking pole of the inducing magnet leaves last? Why does it lessen the intensity of magnetization of two bar magnets to keep them with their like poles opposite and close together? How can the poles of a magnet be reversed?

(4) Support a piece of magnetized watch spring on a ring of a stand or hold it with crucible tongs, and heat it throughout its entire length to redness with a Bunsen flame for a few moments. When it is cool, test it for magnetization both by iron filings and by a magnetoscope.

(5) If a steel needle is balanced on a horizontal axis and then magnetized, it will point downward when the axis is placed east and west. Your instructor will tell you the angle (*dip* or *inclination*) for your locality. Remove the rod from a ring stand, or use a poker or other long iron rod. Test the ends of the rod for polarity with a magnetoscope, and, in case it is found, mark the north-seeking pole of the rod with chalk. If neither end repels the poles of the magnetoscope, the rod is not magnetized; in that case mark either end. Hold the marked end down and northward in a north and south direction in such a way as to make with the horizon an angle about equal to what you judge the dip to be, and, while it is in this position, tap it on the side a dozen or so times with the base of the stand, with a hammer or with another rod. Test the rod again for polarity. Hold the rod with its marked end up, pointing southward and making an angle with the horizon equal to the dip, and tap it much longer than before. Test the rod for polarity again. Repeat until you are sure of the results. Is the north-seeking pole of the magnet made by the inductive action of the earth produced at the lower or the upper end of the rod in the Northern Hemisphere?

(6) Break or cut a long magnetized watch spring, the position of the poles of which are known, into two pieces. Test for polarity by iron filings and by a magnetoscope.

(7) Mark the poles and divide each piece again, testing as before.

(8) Laying the pieces on a sheet of paper in their original positions before the spring was cut, show by a sketch the present position of the poles.*

(9) Half fill the ignition tube with iron filings, and close it with a cork flush with the end of the tube. Shake the tube until the filings lie evenly all along the tube when held horizontally. Place the north-seeking pole of a bar magnet below the center of the tube and draw it slowly to the right until it leaves the tube. Then place the south-seeking pole in the center and draw it in similar fashion to the left. Repeat the motions of the bar magnet several times.

(10) Without disturbing the filings, bring one end of the tube up to a magnetoscope and ascertain its polarity. Also test the other end of the tube. Shake up the filings and again test for polarity. How do you account for the behavior observed?

* Consult some text to learn the bearing of the results obtained on the theory of magnetization.

EXPERIMENT XLIX

MAGNETIC FIELDS

What to use. Two bar magnets. Horseshoe or U-magnet. Magnetoscope or compass. Wood blocks of the same thickness as the magnets. Large sheets of smooth paper. (If permanent records are to be made, blue print paper will be needed.) Iron filings. Large iron washer of the same thickness as the magnets.

I. *To trace the direction of a magnetic line of force.*

What to do. (1) Spread the paper out upon the table and, placing the compass near its right-hand edge, shift the paper until that edge is parallel with the direction of the needle. Do not have the bar magnet near enough to influence the needle.

(2) Lay the bar magnet in the center of the paper with its north-seeking pole to the north and with its axis parallel to the edge of the paper, thus placing it in the magnetic meridian. Draw a pencil line around the magnet to outline its position.

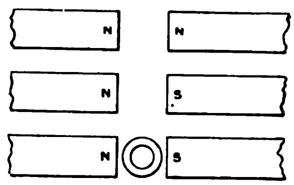
(3) Bring the compass near the north-seeking pole on one side of the magnet and mark dots vertically below the ends of the compass needle. Move the compass away from the magnet until the end that was nearest the magnet is vertically above the dot farthest from the magnet. Mark this new position with dots. Continue moving and marking the direction of the compass until the edge of the paper is reached, and continue around until the compass arrives at the south-seeking pole. Join the dots by a smooth curve, and indicate by an arrow head the direction of the north-seeking pole of the compass when placed upon this line.

(4) *Optional.* In similar fashion map other lines of force. It is not necessary to locate the dots with too great an expenditure of time, for the curve will reduce the error a good deal. Construct the lines of force on both sides of the magnet.

II. *To map a magnetic field.*

(5) Lay a bar magnet upon the table, cover it with a piece of smooth paper, and make the surface of the paper level by slipping under it wood blocks for props.

(6) Holding the shaker as high above the paper as possible, sprinkle the filings upon the paper as evenly as you can, tapping the paper lightly in order to aid the filings to place themselves along the lines of force. Do not use too many filings; the appearance should be gray rather than black. Sketch the outlines of the field thus mapped.



(7) Map and sketch the fields when the magnets are placed as shown in the figure.

(8) How does the appearance of the field mapped with the iron washer between unlike poles show that magnetic lines of force pass more readily through iron than through air?

Blue Prints. Permanent records of the fields may be made as follows: Prepare the field in a very feeble light on blue print paper placed on a board or a pane of glass. Then carry the board without disturbing the filings into sunshine and leave it there until the exposed part of the paper has turned brown or a bronze color. Brush off the filings and soak the paper in water for about ten minutes. Smooth the paper out on a pane of glass and let it dry there.

EXPERIMENT L

THE SIMPLE VOLTAIC CELL

What to use. Strips (elements) of sheet zinc and of copper, about 2 × 10 cm. Clamp for holding the strips within a tumbler. Magnetic needle. About 50 cm. of insulated wire. Two plates or trays, one containing a little mercury. Emery or sand paper. Dilute (5 to 10 per cent) sulphuric acid.

To transform chemical energy into electrical energy.

What to do. (1) Rub the strips with emery paper until bright.

(2) Fill the tumbler about two-thirds full of the acid, and place the zinc strip in it. The appearance of bubbles of hydrogen (a constituent of the acid) is evidence that a chemical action takes place.

(3) Remove the zinc strip, laying it upon a plate, and repeat (2) with the copper strip. What evidence is there that the copper is acted upon by the acid?

(4) Put both strips into the acid, and, keeping their bottoms apart, press their tops firmly together. Where is hydrogen now evolved?

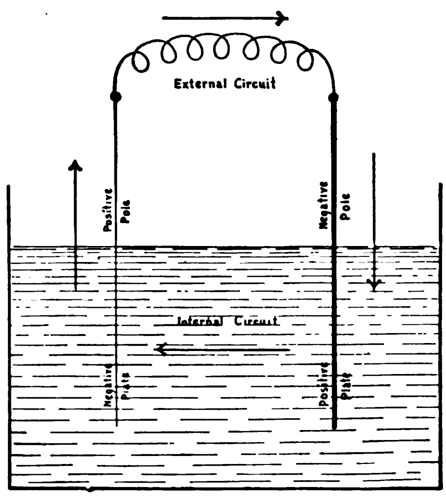
(5) Rub a *very little* mercury over the wet portion of the zinc strip in such a way as to cover it with a thin, mirror-like coating. Be careful not to let any mercury get upon the copper strip.

(6) Put the zinc strip thus *amalgamated* back into the acid, and compare its behavior with that observed in (2). Repeat (4) with this amalgamated zinc. On which plate does the hydrogen now appear?

(7) Fasten the strips in the clamp and put them into the acid. Connect the two binding posts by the insulated wire, thus *closing the circuit.* Compare results with those obtained in (6).

(8) *Break the circuit* by disconnecting one of the ends of the wire from the clamp. Bring the wire down over and parallel to the magnetic needle, and then close the circuit. How is the presence of a magnetic field shown? This magnetic field is due to a current of electricity in the wire. By means of voltaic cells, chemical energy is converted into electrical energy.

(9) Examine any copper and zinc plates that have been used for some time in a cell of any kind. Which of the plates shows evidence of chemical action?



Remarks. The plate that is consumed by the acid is called the *positive plate* and the one not acted upon is called the *negative plate.* The direction of the current within the liquid (the *internal circuit*) is from the positive plate to the negative plate, while outside the liquid (the *external circuit*) the current has the opposite direction. The part of the positive plate outside the liquid is the *negative pole,* and the corresponding part of the negative plate the *positive pole.* Starting from the positive pole, the direction of the current is: positive pole to external circuit to negative pole to positive plate to internal circuit to negative plate to positive pole again.

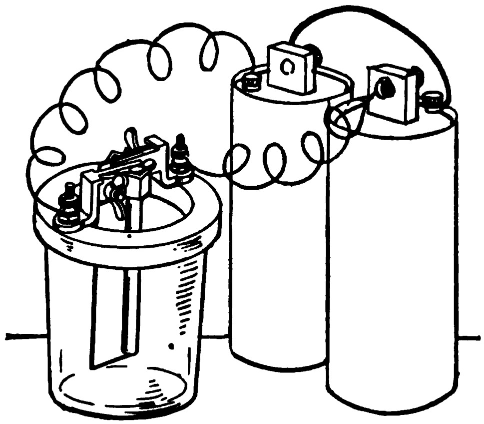
EXPERIMENT LI

CHEMICAL EFFECTS OF CURRENTS

What to use. Two dry cells or their equivalent. One 10 cm. and two 30 cm. connecting wires. Tumbler containing copper sulphate solution, and one containing very dilute (about 2%) sulphuric acid. Two 20-penny nails. Two pieces of electric light carbons, or carbon plates. Two nickel coins. Two paper clips. Sand or emery paper.

To transform electrical energy into chemical energy.

What to do. (1) Connect the positive (carbon) pole of one cell with the negative pole (zinc) of the other by the short wire, thus joining the cells in series. Sandpaper the nails as well as the bared ends of the longer wires until they are bright. Wrap tightly three or four turns of each of the bared ends of the wire around each of the nails just below their heads, and connect the other ends of the wires to the terminals of the battery. Or, put the nails in the clamp of the demonstration cell of Experiment L and connect them by means of the binding posts and the wires to the battery.



(2) Dip the ends of the nails (*electrodes*) into the sulphuric acid, thereby closing the circuit. The gas that is evolved the more abundantly is hydrogen; the other gas is oxygen. At which electrode, that connected with the positive or with the negative pole of the battery, is the hydrogen given off? The electrode where the hydrogen appears is called the *cathode*; that where the oxygen appears, the *anode*. What kind of charge — positive or negative — must the hydrogen ions carry? Interchange the connections of the nails to the battery, and dip the nails again into the acid. What differences in behavior are observed?

(3) Substitute the carbon rods for the nails and dip them into the copper sulphate solution. After a minute or two remove the carbon electrodes and note what has happened to one of them. What kind of charge do the copper ions in the solution carry? Interchange the connections and observe what takes place. The process observed illustrates *electroplating*.

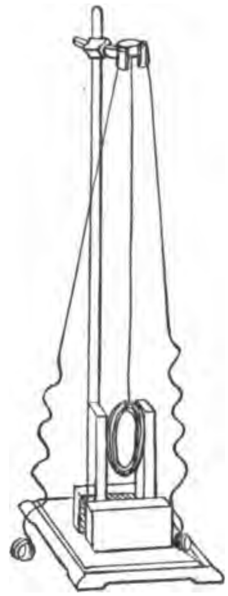
(4) *Optional.* Fasten a nickel by means of the paper clips to each of the wires, and immerse the nickels in the copper sulphate solution. Let the action proceed for a minute or so, and then interchange the positions of the two nickels.

To remove most of the copper from a plated nickel, connect it with a carbon electrode in such a manner that the plating of copper will be transferred from the nickel to the carbon.

EXPERIMENT LII

MAGNETIC EFFECTS OF CURRENTS

What to use. Simple cell. Commutator. Compass. U-shaped magnet fastened upright on a base. Soft iron rod. Two 30 cm. connecting wires. Connecting wire about .5 mm. in diameter and at least 2 m. long. D'Arsonval coil. (Wind about 100 turns of very fine insulated copper wire around three fingers of the hand in such a way as to form a flat coil with straight ends about a meter long. Slip the straight wires in a split cork held by the clamp of a stand so that the coil hangs between the poles of the U-magnet set on the base of the stand.)



I. *To study the magnetic field produced by a straight wire through which a steady current is passing.*

What to do. (1) Connect the binding posts of the top part of the commutator to the cell by means of the short wires, and join the binding posts of the bottom part by the long wire. Be sure that the insulation is stripped from the ends of the wires, and that the contacts are clean. Bring a portion of the long wire close over and parallel to the needle of the compass. Close the circuit at the commutator, and note whether the north-seeking pole of the needle turns to the west or to the east. To save the cell, keep it on open circuit, or, better, lift the plates out of the acid, except when actually making an observation.

(2) Reverse the direction of the current at the commutator, and note the direction the needle deflects. Evidently the current-carrying wire is surrounded by a magnetic field the direction of the lines of force of which depends upon the direction of the current.

(3) Trace out the direction of the current, and, grasping the wire in the right hand near the compass so that the thumb points out the direction in which the current flows, compare the direction the N-pole of the compass turns with the direction the fingers of the clenched hand point. By definition, the direction the N-pole turns is the direction of the lines of force. Derive then the so-called right-hand rule, a great help in remembering and testing the relation between the direction of the magnetic lines of force encircling a wire and the direction of the current producing them.

(4) Hold the wire in such a way that the current flows vertically downward in front of the N-pole of the needle, and see if the rule applies. Repeat when the current is flowing vertically upward.

(5) Hold the wire over the center of the compass so that the current flows from west to east. Note what occurs, and then reverse the direction of the current. How does the result show that the lines of force are in planes at right angles to the wire?

(6) Repeat (1), (2), (3), and (4) with the wire below and parallel to the needle. Repeat (5) with the wire below and at right angles to the needle. Test the right-hand rule in every case.

(7) Holding the wire as close as possible to the compass, send a current through it from north to south, and read the angle of deflection. If this is more than 30°, lift the

zinc plate up so as to decrease the chemical action and thereby weaken the current. Loop the wire vertically around the compass so that the current flows from north to south above the compass and from south to north below, and read the deflection.

(8) Wind two turns of the wire around the compass and compare the amount of the deflection with that observed for a single turn. Increase the number of turns and note what change in the amount of deflection each additional turn occasions. Such an arrangement constitutes a *fixed-coil galvanometer*.

(9) With a single loop around the compass and held parallel to the needle, lift the zinc plate up until the compass needle barely moves when the circuit is made or broken. Without changing the adjustment of the zinc plate, put a half dozen or so turns of the wire vertically around the compass and note the deflection when the current is made. How may the *sensibility*, that is, the ability to detect weak curents, of a galvanometer be increased?

(10) *Optional.* Spread a paper or your handkerchief over the cell so as to hide the connections, and have another student adjust the commutator so that you will not know the direction of the current. Try to find out its direction by the aid of a compass, *write down* your results, and then test its correctness after uncovering the cell.

TABULATION

When Current Flows	N-Pole of Needle Turns*
Northward above compass	
Northward below compass	
Southward above compass	
Southward below compass	

II. *To study the magnetic field produced by a current-carrying coil of wire.*

(11) Wind the long wire in a close spiral around the soft iron rod, leaving the straight ends about 25 cm. long. Remove the iron rod, and bring first one end and then the other end of the *helix* or *solenoid*, while a current is passing through it, up to the N-pole of the compass. Note the direction in which the needle turns. Reverse the direction of the current, and again test the polarity of the coil. If the needle is not moved very perceptibly, substitute a fresh cell or some form of commercial cell for the simple cell already used.

(12) Grasp the helix in the right hand in such a way that the fingers point out the direction in which the current is flowing around the coil. Towards which pole of the solenoid does the extended thumb point? Show how this result should follow from the right-hand rule for a straight wire.

(13) Put the soft iron rod back into the helix and test the polarity of the *electromagnet* thus made. Is the magnetic action more or less intense with or without an iron core? Reverse the direction of the current and observe the effect upon the poles of the electromagnet. Change the iron core end for end without altering the direction of the current. Are the poles reversed by such a change?

(14) In the foregoing work the permanent magnet (compass needle) has been free to move while the current-carrying wire has been fixed when an observation was taken. Let us now study the case in which the permanent magnet is fixed and the wires are free to move. Hang the D'Arsonval coil to the support so that it comes between the poles of the U-magnet with the plane of the coil parallel to a line joining the poles of the

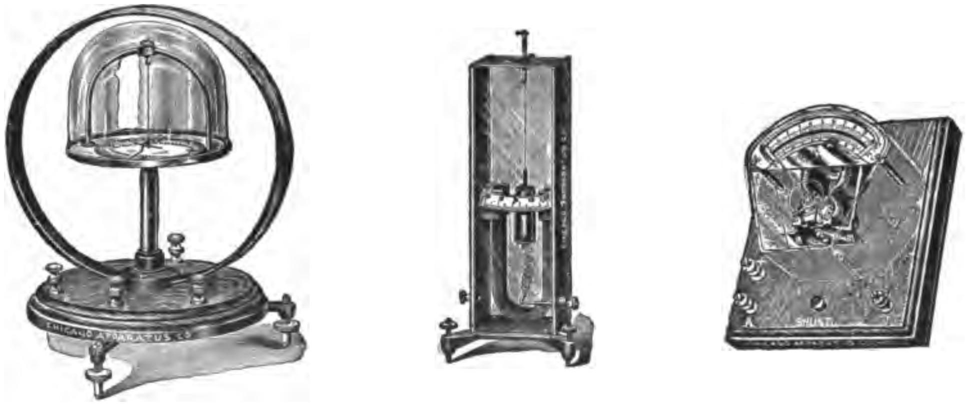
* Indicate by east or west.

magnet. Put a cell and a commutator in the circuit with the D'Arsonval galvanometer thus improvised.

(15) Close the circuit for an instant and note in which direction (from or toward you) the right side of the coil turns. Reverse the current and note which way the turning takes place. At which face of the coil is a N-pole developed? Apply the rule of (12) and find out in which direction — clockwise or counter-clockwise — the current is circulating in the coil.

(16) Turn the magnet (or the suspension of the coil) until the plane of the coil is perpendicular to the line joining the poles. Close the circuit and note the effect. Reverse the current and note the effect. Account for these effects.

(17) Turn the magnet around, without disturbing the coil, until N- and S-poles interchange places. Close the circuit and note the direction in which the coil rotates. Reverse the current and note the effect upon the coil.



COMMERCIAL GALVANOMETERS

Tangent Galvanometer. Examine the construction of a tangent galvanometer. Note the leveling screws that serve to adjust the instrument to any inequalities or lack of level of the table top so that the pointer may swing freely over the scale. Note the suspension made of a single silk fiber which is a very strong and light substance. Why is the pointer fixed at right angles to the magnet, and why is it longer than the magnetic needle? Note the binding post at the back of the instrument to which one end of each of the windings is connected. Note the three binding posts in front of the instrument to which the other ends of the windings are severally joined. Coil "4" has four turns of copper ribbon or coarse wire; coil "50" has 50 turns of copper wire of medium size; and coil "500" has 500 turns of very fine copper wire. Each of the coils serves a special purpose, as will be shown in subsequent experiments.

D'Arsonval Galvanometer. Examine the construction of a D'Arsonval galvanometer. Note the coil made of very fine copper wire (its resistance is 100 ohms) wound around a light metal frame. The frame lessens the time of vibration, making the coil more "dead-beat" — an application of eddy currents. Note the soft iron cylinder fastened within but independently of the coil; it serves to collect the lines of force of the magnet and to direct them through the coil. Note the suspension made of phosphor bronze, a very strong and elastic alloy. Why is the flat form better than a round form? Why must the suspension be made of a conductor instead of a nonconductor as in the case of the tangent galvanometer? Note that the current from one binding post passes through the metal parts of the instrument to the device for adjusting the suspension, and that the other binding post is insulated by rubber washers from the case, and is connected by a phosphor bronze ribbon wound in a loose spiral (Why?) to the coil.

Voltmeter and Ammeter or Volt-ammeter. The best of these instruments are forms of D'Arsonval galvanometers. Note the shape of the case and the direct graduation into volts and amperes. The instructor will tell you how to use the instrument properly. Note that the suspension of the coil is a steel point with a jewel bearing, and that a hair-spring regulates the movements of the pointer.

EXPERIMENT LIII

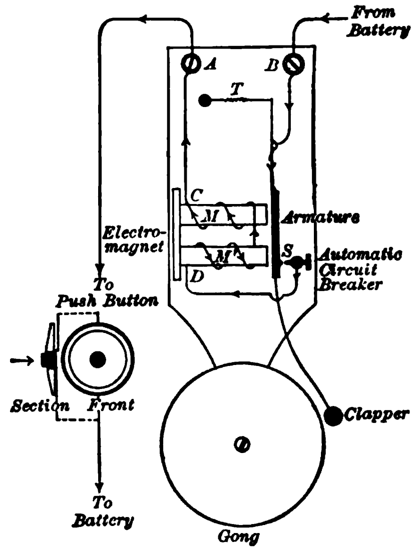
THE ELECTRIC BELL

What to use. Iron box electric bell with the gong removed or with a bit of rubber tubing slipped over the clapper to deaden the noise. Key or push button. Dry cell. Three 30 cm. connecting wires. Small screw-driver (a knife blade or a small rectangle of stiff sheet brass or of steel will answer).

To study the construction and action of a vibrating bell.

What to do. (1) Take off the cover so as to expose the inside of the bell. Note the electromagnet, the soft iron armature with the clapper attached to its one end and the spring to the other.

(2) Connect one binding post of the bell to a binding post of the cell, and the other to a binding post of the key (if a push button is used, unscrew its top and examine into its construction). Connect the second binding post of the cell to the key. Press down on the key for a moment. If the clapper does not vibrate, turn in or out the set screw until its platinum tip is lightly touching the spring brass tongue fastened to the armature. If the clapper still does not vibrate, when the circuit is closed, make another adjustment of the set screw. Continue adjusting this screw until the clapper vibrates readily on closing the circuit. Note the sparks passing between the platinum point of the set screw and the brass tongue. By means of the lock nut, clamp the set screw in the position where the clapper acts the best.



(3) Turn the bell over and, starting from the binding post that is insulated from the metal base by means of a rubber washer and is connected with the electromagnet by wire covered with rubber tubing, trace the circuit through the various parts to the other binding post. Bear in mind that the metal base forms a part of the circuit.

(4) Study the bell in action. What changes would have to be made in its construction in order to convert it into a single-stroke bell, like a telegraphic sounder?

(5) Make a diagram of the circuit through the bell, marking on it the locations of the connections at the two binding posts, at the post having the set screw, and at the post on which the armature turns. Indicate by a dotted line the parts of the circuit formed by the metal base.

(6) *Optional.* Draw a diagram of a circuit including a bell, a cell, and two key or push buttons connected in such a way that pressing either key will make the bell ring. Connect up the apparatus in accordance with your diagram, and see if it will work.

(7) *Optional.* Draw a diagram of a circuit including a key, a cell or battery, and two bells so connected that both bells will ring when the circuit is closed. Connect up the apparatus and test its working.

EXPERIMENT LIV

AN ELECTROMOTIVE SERIES

Potential Difference. A difference of potential *P. D.* is found to exist between a conductor and a conducting liquid in which it is immersed, and the amount of this difference depends upon the nature of the substances in contact. The *P. D.* between zinc and sulphuric acid, for instance, is different from that between copper and the acid. If zinc and copper be put into the same supply of acid, a *P. D.* between the two metals will be set up, and a current will pass between them if they are connected by a conductor so as to form a closed circuit. To get a steady current, one, at least, of the conductors must be acted upon chemically by the liquid, so that there may be a continued transformation of chemical energy into electrical energy. The essentials of a voltaic cell are two dissimilar metals, one of which, at least, is acted upon by the liquid in which they are placed. The purpose of this experiment is to compare the direction and amount of the current produced by voltaic cells made up of various materials with that produced by the standard combination — zinc — dilute sulphuric acid — copper — zinc.

What to use. Strips (elements) about 2 × 10 cm. of zinc, copper, lead, iron, and of aluminum. Carbon plate or a piece of electric light carbon. Tumbler. Two 50 cm. connecting wires. Dilute (5 %) sulphuric acid. Solutions of various salts, acids, or bases, as provided by the instructor. Galvanometer or voltmeter. Emery or sandpaper. Two plates or trays.

To compare the direction of the currents produced in voltaic cells made up of various plates and liquids.

What to do. (1) Rub the strips bright with emery paper. Fill the tumbler about two-thirds full of the sulphuric acid. Connect the two wires with a galvanometer or voltmeter. (If a tangent galvanometer is employed, use the 500-turn coil.)

(2) Press the bared ends of the wires not connected to the galvanometer against a zinc and against a copper strip, one in each hand, and immerse the strips in the acid. Note the direction in which the north-seeking pole of the magnetic needle turns, bearing in mind that the direction of the circuit is from the copper to the zinc outside of the acid. If the galvanometer has a scale, read the number of degrees of the deflections.

(3) Repeat (2), substituting a lead plate for the copper plate. If the needle is deflected in the same direction as in (2), the current flows from lead to zinc in the external circuit; and lead therefore forms the positive pole of such a combination. But if the needle is deflected in the opposite direction, the lead is the negative pole. Test zinc with aluminum, with carbon, and with iron, recording the results as follows:

Zinc	−	Copper	+	Deflection 18°
Zinc	?	Carbon	?	Deflection ?
Zinc	?	Lead	?	Deflection ?
Zinc	?	Aluminum	?	Deflection ?
Zinc	?	Iron	?	Deflection ?

(4) Substitute a lead plate for the zinc and test the lead with copper, with carbon, with aluminum, and with iron. Record as above. Proceed in like manner to get all the possible combinations of the pairs of metals.

(5) Arrange the substances in a list so that each substance will be positive with respect to any one following it but negative with respect to any one preceding it. Such a list is called an Electromotive Series.

(6) Immerse zinc and copper in any other of the liquids provided, and record the deflection in each case. Rinse off the plates very thoroughly before immersing them in a fresh liquid. Try other combinations of metals in the different liquids.

EXPERIMENT LV

POLARIZATION OF CELLS

What to use. Tangent galvanometer having a coil of about 250 ohms resistance (a D'Arsonval galvanometer or a voltmeter may be used instead). Two copper strips. Two carbon rods or plates. Amalgamated zinc strip. Tumbler with clamp for holding the strips. Two 50 cm. connecting wires. Tray or plate. Dilute solution of sulphuric acid (2 to 3 per cent). Strong solutions of chromic acid (or potassium dichromate) and of copper sulphate. Pipette or medicine dropper. Emery or sandpaper. Watch.

To ascertain the cause and the remedy for the polarization of cells.

What to do. (1) Connect the galvanometer with the clamp in which is inserted a copper and a zinc strip. The copper plate should be polished bright, and, if it has been recently used, it should be heated in a Bunsen flame before polishing. Put the plates into the acid and, as soon as possible, note the angle through which the pointer turns. Take a reading every minute for five minutes. Does the current stay constant or does it become weaker?

(2) Take the copper strip out of the acid without disturbing the connections or the galvanometer; much of the hydrogen on it will pass off into the air. Then put the plate back into the acid and note the deflection as promptly as possible. What effect does the hydrogen that gathers on the plate have upon the strength of the current?

(3) Place a copper strip in contact with the upper ends of the zinc and copper strips in the acid in such a way as to short circuit the cell. How does the amount of hydrogen now evolved compare with that evolved in (1)? Why does the pointer return nearly to zero while the cell is short circuited? At intervals of about a half minute, remove the short-circuiting strip and read the galvanometer.

(4) When the deflection has been reduced to three-fourths or less of its first value, take out the zinc strip and put a fresh copper strip [prepared as in (1)] in its place. Look very carefully for any movement of the pointer. By lifting the fresh strip out of the acid and then putting it back quickly, any small movement of the pointer can be detected. In what direction is the current in this cell made up of a copper plate covered with hydrogen and a copper plate on which there is no hydrogen?

(5) Put the zinc strip back again and short circuit the cell until the deflection is the same or less than in (3). Remove the short-circuiting strip. Take about 5 $cm.^3$ of copper sulphate solution up in a pipette, and deliver it into the acid around the copper plate. What effect does the addition of this depolarizer have upon the deflection of the galvanometer? Short circuit the cell again for a couple of minutes and then read the deflection. If it is not the same, add a little more of the depolarizer.

(6) Repeat (1), (2), (3), and (4) with carbon instead of copper plates. Repeat (5), using carbon instead of copper, and chromic acid solution instead of copper sulphate solution.

(7) *Optional.* Substitute a dry cell or a Leclanché cell for the simple cell. Note whether the strength of the current decreases when the circuit is closed for three minutes. Short circuit the cell by pressing a copper strip upon its poles for a minute, then remove the strip and note the deflection.

EXPERIMENT LVI

THE TANGENT GALVANOMETER

Deflection and Strength of Current. If the plane of a vertical coil of wire be set in the magnetic meridian, and a compass placed at the center of the coil, the strength of the current will be proportional not to the angle through which the pointer turns but will be proportional to the trigonometrical tangent (see page 95) of that angle. For example, suppose that a current of two amperes, when passed through such a coil, produces a deflection of 61°, and that another current of unknown strength produces a deflection of 42°. Since the tangent of 61° is 1.8 and the tangent of 42° is .9, we have, denoting the strength of the unknown current by x, the proportion:

$$\begin{aligned} 2 : x &= \tan 61^\circ : \tan 42^\circ \\ &= \quad 1.8 : \quad .9, \end{aligned}$$

whence $x = 1$ ampere. Such an arrangement for measuring current strengths is called a tangent galvanometer.

If we know the deflection which a current of known strength produces in a certain tangent galvanometer, the strength of any other current may be found by measuring the deflection that it causes. Since the tangent of 45° is 1, it simplifies calculations to determine first the strength of current that produces a deflection of 45°. The value of such a current is called the *reduction factor* or *galvanometer constant.* Let k denote the reduction factor and a the deflection produced by a current of unknown strength c. Then

$$\begin{aligned} k \cdot c &= \tan 45^\circ : \tan a \\ &= \qquad 1 : \tan a, \end{aligned}$$

whence $c = k \times \tan a$, and $k = c/\tan a$. Each coil of the galvanometer has its own reduction factor.

Ammeters. If the scale of a galvanometer is graduated not in degrees of arc but in amperes, the galvanometer becomes an ampere-meter or *ammeter.* As all the current must pass through an ammeter, its resistance is made small; otherwise it would itself absorb too much of the current. The coils are therefore made of a few turns of coarse wire.

Voltmeters. If the scale of a galvanometer is graduated in volts instead of degrees of arc, a voltmeter results. As voltmeters are placed on shunt circuits and should permit but a very small current to pass through them, their coils are made of many turns of fine wire so as to offer a great resistance. The currents that pass through voltmeters are so slight that they may be taken as equal to the E. M. F's, and the deflection interpreted as being a measure of E. M. F. instead of current strength.

Windings of Tangent Galvanometer. While most commercial ammeters and voltmeters are direct reading galvanometers of the fixed magnet type, by appropriate winding of a tangent galvanometer it may be used to advantage as a means of comparing strengths of currents and electromotive forces. Three windings as follows will be found to meet the requirements of this course:

Winding I. Four turns of copper wire or ribbon about 2 mm. in diameter, having a resistance of about .02 ohm and a reduction factor of about 1. It is to be used in comparing currents from .5 to 15 amperes.

Winding II. Fifty turns of wire about 1.3 mm. in diameter, having a resistance of about .5 ohm and a reduction factor of about .07. It is to be used in comparing currents from .05 amperes to .5 amperes.

Winding III. Five hundred turns of wire about .2 mm. in diameter, having a resistance of about 250 ohms and a reduction factor of about .007. It is to be used in comparing E. M. F's as well as currents from .005 to .02 amperes.

RULES FOR USING A TANGENT GALVANOMETER

I. Place the instrument with its coils in the magnetic meridian, level it so that the pointer swings freely over the scale, and turn the compass so as to bring the ends of the pointer to zero. The needle is at right angles to the pointer and will then be in the magnetic meridian. When once adjusted, do not disturb the instrument during the course of an experiment.

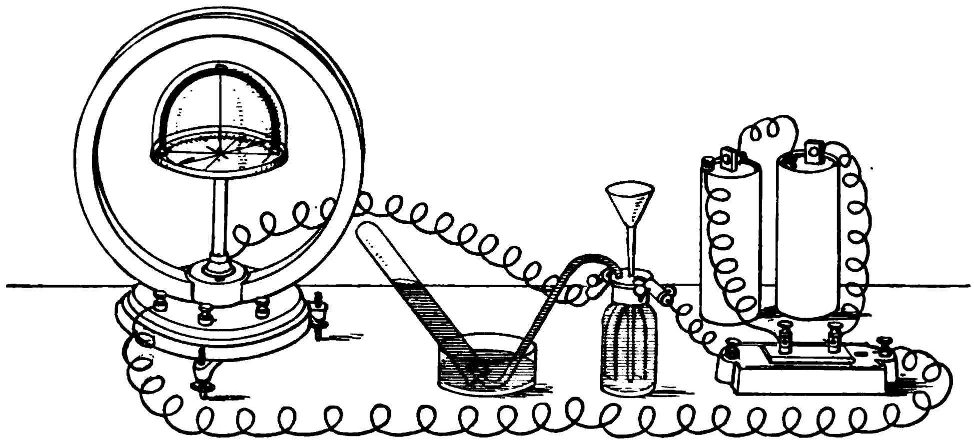
II. If a commutator is put in the galvanometer circuit, frequently reverse the current through the coils during an experiment. Read the position of both ends of the pointer, and take the average of the direct and reversed readings (an equal number of each) as the true deflection. By so doing any slight errors in the construction and adjustment of the instrument are eliminated.

III. Avoid the errors due to parallax by placing the eye so that the pointer covers its own image in the mirror to which the scale is attached.

Electrolysis. A current of two or three volts when passed into a solution of sulphuric acid or caustic soda causes the evolution of a mixture of two volumes of hydrogen and one of oxygen (*oxyhydrogen gas*). There is a definite ratio between the strength of the current and the volume of the oxyhydrogen gas; one ampere in one second causes the evolution of 1.76 $cm.^3$ of the gas measured at 0° under a pressure of 760 mm. or of about .18 $cm.^3$ at the ordinary temperature and pressure. By measuring the deflection of a tangent galvanometer and the volume of oxyhydrogen gas both due to the same current, the reduction factor of the galvanometer may be found.

Reduction Factor of Tangent Galvanometer

What to use. Tangent galvanometer. Oxyhydrogen voltameter. This consists of a bottle provided with a two-hole stopper through which pass a delivery tube and a funnel tube. Wires pass through the stopper and are joined to two electrodes, while their outer extremities are provided with double connectors. Electrodes of nickel with nickel wires are as good as platinum, if a 10 per cent solution of caustic soda is used, and are much cheaper. Crystallizing dish. Graduated tube. Commutator. Two or three dry cells or their equivalent. Connecting wires. Watch or other time measurer.



To compare the deflection of the needle of a tangent galvanometer caused by a current with the volume of oxyhydrogen gas evolved by the action of the same current; to determine the reduction factor of the galvanometer.

What to do. (1) Set up the apparatus as shown in the figure, using the low resistance coil of the galvanometer, and connecting the two cells in series. Observe all the precautions given above in regard to adjusting the instrument.

(2) Close the circuit at the commutator. If bubbles of gas do not escape from the delivery tube placed below the water in the dish at the rate of one every two or three seconds, the current is not strong enough, and a third cell should be added, also in series. The strength of the current should be such that the galvanometer needle is deflected from 25° to 65°, the best deflection being 45°. (If the old-style instrument is used, the number of turns included in the circuit may be changed so as to make the deflection as near as possible to 45°.)

(3) Fill the graduated tube with water at the temperature of the room, close it with the thumb, invert it, and put its mouth under water in the crystallizing dish. Be sure that there is no air bubble in the upper closed end of the tube. Close the circuit again and read the position that the ends of the pointer take when the needle comes to rest. Reverse quickly the direction of the current and again take readings.

(4) Set the graduated tube over the delivery tube, noting carefully the time of so doing. At the expiration of every minute interval, quickly reverse the current and read the deflections in the opposite direction. When the graduated tube is nearly full of the gas, break the circuit, noting the time of so doing accurately.

(5) Hold the graduated tube vertically in such a way that the level of the water is the same in the inside as on the outside of the tube, and read the volume of gas collected. Calculate the strength of the current in amperes by multiplying the volume by the number of seconds. Compute the reduction factor.

(6) Make a second determination, and, if time permits, even a third one.

TABULATION

Tangent galvanometer, No. .... No. of turns in coil ....

	I			II			III		
	Hr.	Min.	Sec.	Hr.	Min.	Sec.	Hr.	Min.	Sec.
Time electrolysis begins									
Time electrolysis ends									
Duration of electrolysis...................			sec.			sec.			sec.
Volume of gas			cm.^{3}			cm.^{3}			cm.^{3}
Strength of current			amp.			amp.			amp.

Deflection of pointer....................	Direct		Reverse	
	East End	West End	East End	West End
	°	°	°	°
	°	°	°	°
	°	°	°	°
Average.....................				

Tangent of average angle of deflection............. Reduction factor ....

EXPERIMENT LVII

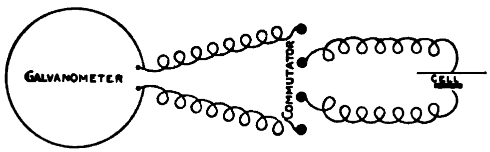
ELECTROMOTIVE FORCE OF CELLS AND BATTERIES

What to use. Various cells, such as the Daniell, the Leclanché, the dry, the bichromate, etc. Tangent galvanometer or voltmeter. Commutator (not necessary, if a voltmeter is used). Four 50 cm. and several 10 cm. connecting wires. [Resistance box may be needed. See (2).]

I. *To compare the electromotive forces of various cells.*

What to do. (1) Set up the tangent galvanometer (see page 141) and connect the 500-turn winding with the lower part of the commutator.

(2) Connect in succession each of the cells with the upper part of the commutator, close the circuit, and read the deflections at both ends of the pointer; then reverse the current and read the reversed deflections. If the average deflection is more than 35° introduce resistance into the circuit until the deflection is reduced to about 30°.



(3) If a voltmeter is used, its readings give at once the E. M. F. of the cells in volts. If the tangent galvanometer is used, the tangent of the angle of deflection is proportional to the E. M. F. and may be taken as a measure of it. Since the E. M. F. of a Daniell cell is very nearly 1.08 volts, the voltage of the other cells may be computed by means of the proportion:

$$\frac{\text{Voltage of cell}}{1.08} = \frac{\text{Tangent of deflection of cell}}{\text{Tangent of deflection of Daniell cell}}.$$

Look up the tangents of the angles of the deflections and compute the voltage of each cell.

II. *To compare the electromotive forces of various combinations of cells (batteries).**

(4) Form a battery of any two of the cells by connecting them in series, that is, by joining the positive pole of one cell with the negative pole of the other cell, and connecting the remaining poles to the commutator. Measure the E. M. F. of this battery and compare it with the E. M. F.'s of each of the cells.

(5) Make a battery of the two cells used in (4) by connecting them in parallel, that is, by joining their negative poles together and then their positive poles. Measure the E. M. F. and compare it with the E. M. F.'s of each of the cells.

(6) *Optional.* Make up batteries of more than two cells joined both in series and in parallel, and compare their E. M. F.'s with those of the individual cells.

* It simplifies the relations if the same kinds of cells are used in making up batteries.

TABULATION *

Tangent galvanometer, No.... 500-turn winding.

Name of Cell	Direct Deflection of Pointer		Reverse Deflection of Pointer		Average Deflection a	Tan a	E. M. F.
	East End	West End	East End	West End			
Battery of (name cells)	°	°	°	°	°		volts

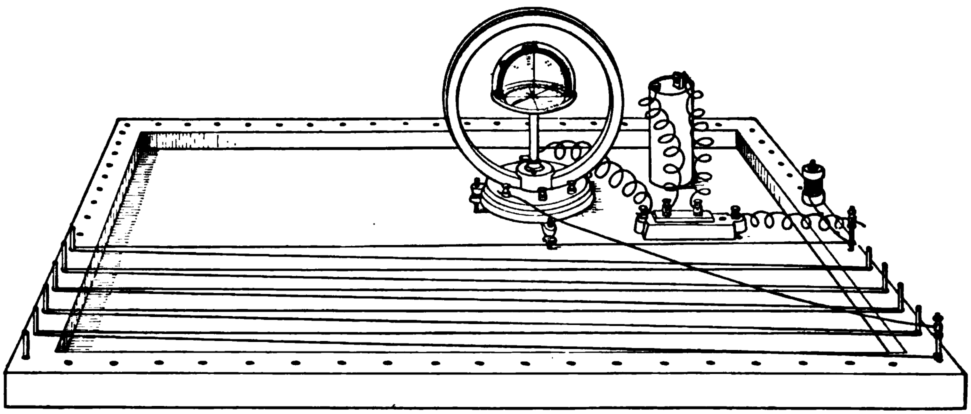
* If a voltmeter is used, only the first and last columns are required.

EXPERIMENT LVIII

LAWS OF RESISTANCE

Strength of Current and Resistance. The strength of a current of water, electricity, or anything else that may be conceived of as flowing is the amount of the flowing thing that passes through the conductor in a given time. In all parts of a series circuit the strength of the current is uniform. Resistance is whatever opposes flow. The greater the resistance the less the flow — is a statement true of electricity as well of such fluids as water or air. In this experiment the length, size, and material of a conductor are changed and the amount of flow of electricity through it is measured. The amount of flow or strength of current is proportional to its magnetic effect, as measured by the tangent of the angle of deflection of the magnetic needle.

What to use. General utility board with pegs and two clamps for making electrical connections. Tangent galvanometer of very low resistance. Commutator. Constant cell (an Edison-Lalande or storage cell is best, although a fresh dry cell will answer, if care be exercised to keep it on closed circuit for as short intervals as possible). Five 30 cm. connecting wires. About 25 m. each of soft iron and of soft brass wire of the same diameter (about .3 mm.) wound smoothly on spools.



General Utility Board with Accessories for Studying Laws of Resistance

To ascertain what effect the length, size, and nature of a conductor has upon its resistance.

What to do. (1) Fasten one end of the iron wire to a peg provided with a slip-over clamp, and string the wire across the board from peg to peg until there are 10 m. of the wire stretched over the board. Do not cut or break the wire but leave the excess on the spool, preventing its unwinding by taking a turn around the tack on the spool. Connect one end of the wire with the 4-turn winding of the galvanometer, and the other end by a slip-over clamp with the base of the commutator. Connect the cell with the top part of the commutator and the other terminal of the 4-turn winding with the commutator.

(2) After adjusting the galvanometer properly, close the circuit and read the scale underneath each end of the pointer. Reverse the current and again read the scale. The tangent of the average of these angles (which should be from 10° to 15°) is proportional to the strength of the current. (If the reduction factor of the galvanometer is known, the deflections can be reduced to amperes.)

(3) Shift the connection between the peg and the commutator to the next peg, thereby cutting 2 m. of the wire out of the circuit. Find the deflection caused by the passage of the current through the 8 m. of the wire. In like manner find the deflections when 6 m. and when 4 m. of the iron wire are included in the circuit.*

(4) Multiply the tangent of each average deflection by the corresponding length of wire. How do the products compare? In what proportion are resistance and length?

(5) String the wire backwards around the pegs in such a way as to get 10 m. of *doubled* wire in the circuit. Find the deflections when 10 m., 8 m., 6 m., and 4 m. of the doubled wire are used. Make the computations as in (4). How does the average of the products of the tangents and lengths in the case of the doubled wire compare with the average of the products of the tangents and lengths in the case of the single wire? How does the resistance of a conductor vary with its size?

(6) Wind the iron wire smoothly upon the spool from off the pegs, being careful not to kink it, and fasten its free end to the tack in the spool.

(7) Repeat with brass wire. Find the ratio of the resistance of iron wire to brass wire.

TABULATION

Law of Lengths

Tangent galvanometer, No.... 4-turn winding

l Length of Single Iron Wire	Direct Deflection		Reverse Deflection		a Average Deflection	tan a	tan $a \times l$
	East	West	East	West			
10 m.	°	°	°	°	°		
8 m.	°	°	°	°	°		
6 m.	°	°	°	°	°		
4 m.	°	°	°	°	°		
							Av.

Law of Diameters

l Length of Doubled Iron Wire	Direct Deflection		Reverse Deflection		a Average Deflection	tan a	tan $a \times l$
	East	West	East	West			
10 m.	°	°	°	°	°		
8 m.	°	°	°	°	°		
6 m.	°	°	°	°	°		
4 m.	°	°	°	°	°		
							Av.

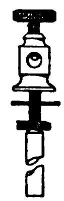
* The resistance of less than 4 m. of the wire will probably be so small that the resistance of the galvanometer and the connections cannot be regarded as negligible, and the results will therefore be indefinite.

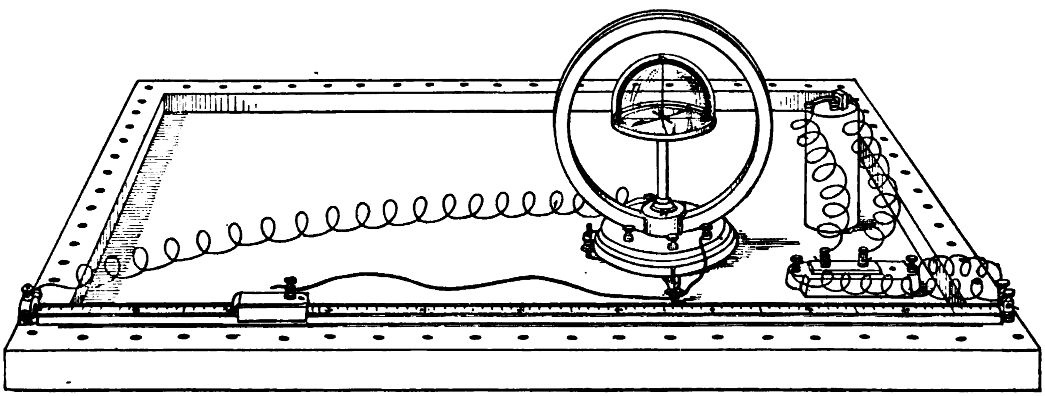
EXPERIMENT LIX

FALL OF POTENTIAL AND RESISTANCE — OHM'S LAW

Principle of the Method. A current of constant strength is sent through a conductor, the parts of which are made up of wires of differing conductivities. The strength of the current is the same in all parts of the conductor. Let such a small fraction of the current be shunted through a voltmeter (high-resistance galvanometer) that the strength of the main current will not be appreciably diminished. The question arises: How does the drop of potential at the terminals of this shunt, as measured by the voltmeter, vary with the resistance between these terminal points?

What to use. A brass and an iron wire of the same diameter (about .3 mm.) stretched along the two edges of the flat side of a meter stick laid upon the general utility board. One end of each of the wires is attached to electric pegs set in the board, and the other ends are fastened to a peg-and-collar clamp. Tangent galvanometer with a coil of at least 250 ohms resistance (a D'Arsonval galvanometer may be used instead; it will need to have a resistance of several thousand ohms included in its circuit, and its deflections may be taken as proportional to the fall of potential). Commutator. Contact block with binding post. Daniell cell (or a dry cell may be used if care is taken to keep it on open circuit as much as possible so that its current may be maintained practically constant). For the optional part a thicker wire (either brass or iron) and micrometer calipers are needed.

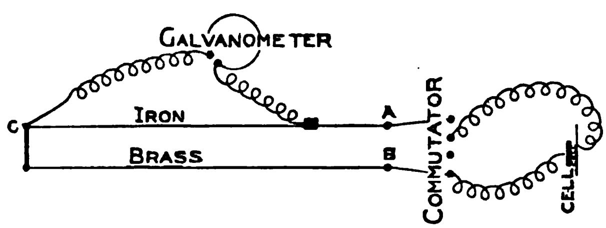




General Utility Board with Accessories for Studying Ohm's Law

To compare the fall of potential along a conductor, traversed by a constant current, with the resistance of the conductor.

What to do. (1) Connect the parts of the apparatus as shown in the figure and the diagram. If a dry cell is used, it should be kept on closed circuit for as brief intervals as possible; but if a Daniell cell is used, its circuit should be kept closed all the time.



(2) Press the block down upon the iron wire so that its edge makes good contact 10.0 cm. from A. Read both ends of the pointer; then reverse the current and read again. (If a D'Arsonval galvanometer is used, the amount of resistance in the galvanometer circuit will have to be increased until the deflection of the pointer is near the limit of the scale. Reverse the current and take the average of the readings, thus eliminating the error due to an inaccurate adjustment of the zero.) The tangent of the average deflection is a drop of potential in 90 cm. of the iron wire.

(3) Repeat (2), making contact at 30.0 cm., 50.0 cm., 90.0 cm. from A, thus including smaller and smaller lengths between the terminals of the shunt circuit. How do the ratios of the angles of the deflections compare with those lengths? In what proportion are difference of potential and resistance?

(4) Repeat (2) and (3) with the brass wire. Divide for each of the equal lengths of both kinds of wire the fall of potential in the iron by the fall of potential in the brass; the quotient gives the number of times greater that the resistance of iron is than the resistance of brass.

(5) *Optional.* Substitute a wire of different size for either the brass or the iron wire so as to have the same constant current pass through two conductors of like material but of different thickness. Repeat (2) and (3) with both wires. Measure their diameters to thousandths of a millimeter with micrometer calipers, and compute their cross-sectional areas. Multiply the falls of potential by the average of tan a/l for each of the wires by its cross-section. How do the products compare? What relation is there between the size of a conductor and the fall of potential in it?

TABULATION *

Diameter of the wires ....

l Length of Wire	Direct Deflection		Reverse Deflection		a Average Deflection	tan a	$\frac{\tan a}{l}$	$\frac{a(\text{iron})}{a(\text{brass})}$
	East End	West End	East End	West End				
90.0 cm.	°	°	°	°	°			
70.0 cm.	°	°	°	°	°			
50.0 cm.	°	°	°	°	°			
30.0 cm.	°	°	°	°	°			
10.0 cm.	°	°	°	°	°			

* For a D'Arsonval galvanometer omit the columns for east and west ends and the column for tan a; the last headings instead of tan a/l will then be a/l.

EXPERIMENT LX

INTERNAL RESISTANCE

Principle of the Method. Let a constant cell, a tangent galvanometer and an adjustable resistance be joined in a series circuit. Suppose that when the external resistance is R_1 ohms (made up of the resistance of the galvanometer R_g, of the connecting wires and binding posts R_w, and of the adjustable resistance R_a), the current strength is C_1 amperes, and that when the external resistance is reduced to R_2 ohms, the current strength is C_2 amperes. Since the electromotive force E and the internal resistance r of the cell remain constant, we have, by Ohm's law,

$$E = C_1(R_1 + r), \text{ and } E = C_2(R_2 + r);$$

whence

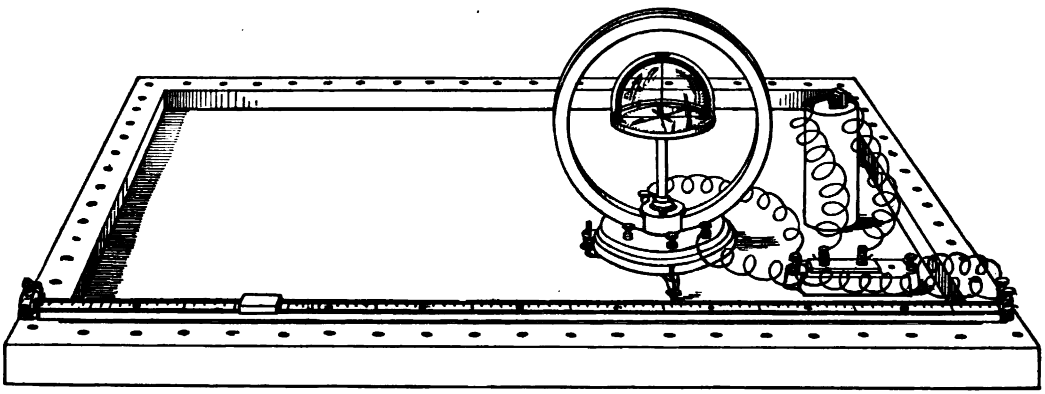
$$C_1R_1 + C_1 r = C_2R_2 + C_2 r,$$

and

$$r = \frac{C_2R_2 - C_1R_1}{C_1 - C_2} = \frac{C_2(R_2 - R_1)}{C_1 - C_2} - R_1$$
$$= \frac{C_2}{C_1 - C_2}(R_2 - R_1) - R_1.$$

When r is found, its value substituted in either of the first two equations gives the value of E.

What to use. Two Daniell or gravity cells. Tangent galvanometer. A piece of German silver wire about .3 mm. in diameter stretched along the two edges of the flat



General Utility Board with Accessories for Measuring Internal Resistance

side of a meter stick laid upon the general utility board. The middle of the wire is fastened to a peg-and-collar clamp and the two ends are connected with binding posts set in the board. A contact block wide enough to reach across the meter stick so as to touch both parallel branches of the wire (a metal strip will answer). Three connecting wires as short and thick as possible. (A resistance box may be substituted for the German silver wire.)

To determine the internal resistance and the electromotive force of a Daniell cell.

What to do. (1) Join the cell in series with the German silver wire (or resistance box) and the galvanometer. Use the 4- or the 50-turn coil of the galvanometer according to which gives a deflection of between 50° and 60° when the contact block is pressed between the two binding posts of the German silver wire (or resistance box) in such a way as to short circuit the cell. Be sure that the galvanometer is properly set up and that

one end of the pointer points precisely to zero; also that the contact block is pressed firmly down.

(2) Read the position of the pointer when the cell is short circuited, that is, when the only resistance in the circuit is that of the cell, the galvanometer and the connections. The tangent of this angle is proportional to the strength of the current C_1.

(3) Keeping the circuit closed, move the contact block away from the binding posts until the angle of deflection is reduced to a value the tangent of which is one-half that of the angle observed when the cell was short circuited. The current passes through the contact block (of negligible resistance) across from one branch of the wire to the other. The length of wire introduced into the circuit is therefore twice the distance between the contact block and the binding posts. (If a resistance box is used, take out such plugs as will reduce the deflection as stated above.) The strength of the current C_2 is now one-half what it was before. Read to millimeters the distance of the block from the binding posts.

(4) Repeat (2) and (3) twice.

(5) The external resistance is equal to the sum of the resistance of the galvanometer (which is marked on the base of the instrument) and of the resistance of the German silver (known or be computed from the resistivity, size and length of the wire) or of the resistance box. The resistance of the connections is negligible. Should the resistance of the galvanometer be less than .1 ohm, it may also be neglected, so that in the last equation, R_1 vanishes, and

$$r = \frac{C_2 R_2}{C_1 - C_2};$$

since C_2 is half C_1, it follows that $r = R_2$. Compute the internal resistance from the formula, and see how much it differs from being equal to the external resistance added.

(6) *Optional.* Repeat all the work (*a*) with the other cell; (*b*) with the two cells joined in series; (*c*) with the two cells joined in parallel.

TABULATION

Galvanometer No. ...... Resistance of ...... coil ...... ohms Kind of cell ......

One cm. of No. 30 (.254 mm.) German silver wire has a resistance of .065 ohm

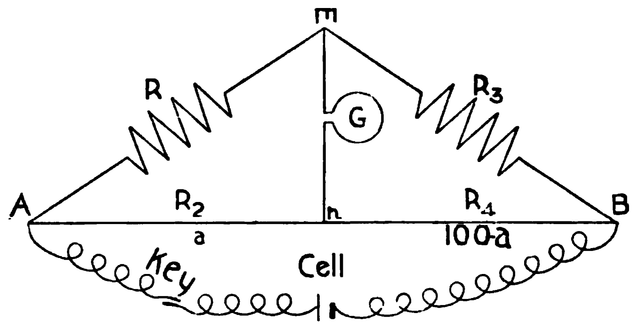
Deflection on Short Circuit	Deflection with Resistance Inserted	Length of G. S. Wire	Resistance of G. S. Wire	Resistance Box
°	°	cm.	ohms	ohms
°	°	cm.	ohms	ohms
°	°	cm.	ohms	ohms
Average				

Internal resistance computed from the formula .... ohms
Internal resistance equal to the external resistance .... ohms
Per cent of difference .... %

EXPERIMENT LXI

RESISTANCE BY THE WHEATSTONE BRIDGE METHOD

Principle of the Method. Let a part of the external circuit of a voltaic cell consist of two branches, so that the current divides at A and reunites at B. A will be at a higher potential than B, and the fall of potential in both branches will be the same. Let each branch include two adjustable resistances, R_1 and R_3, and R_2 and R_4, respectively, and let a wire be connected at a point m between R_1 and R_3 to a point n between R_2 and R_4 so as to form a bridge between the two branches. Let a galvanometer G be placed in



this bridge in order to detect any current that may pass between the two branches. Now it is possible to so adjust the four resistances R_1, R_2, R_3, and R_4 that no current will pass through the bridge, and in that case the points at m and n will be at the same potential. Inasmuch as the same current flows through R_1 and R_3, by Ohm's law,

$$\frac{P.D.\text{ in }R_1}{R_1} = \frac{P.D.\text{ in }R_3}{R_3}; \tag{1}$$

and, since R_2 and R_4 are both traversed by the same current,

$$\frac{P.D.\text{ in }R_2}{R_2} = \frac{P.D.\text{ in }R_4}{R_4}. \tag{2}$$

But if there is no difference of potential between m and n,

$$P.D.\text{ in }R_1 = P.D.\text{ in }R_2,\text{ and }P.D.\text{ in }R_3 = P.D.\text{ in }R_4. \tag{3}$$

Dividing equation (2) by equation (1) and eliminating the equal $P.D.$'s, we have

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \tag{4}$$

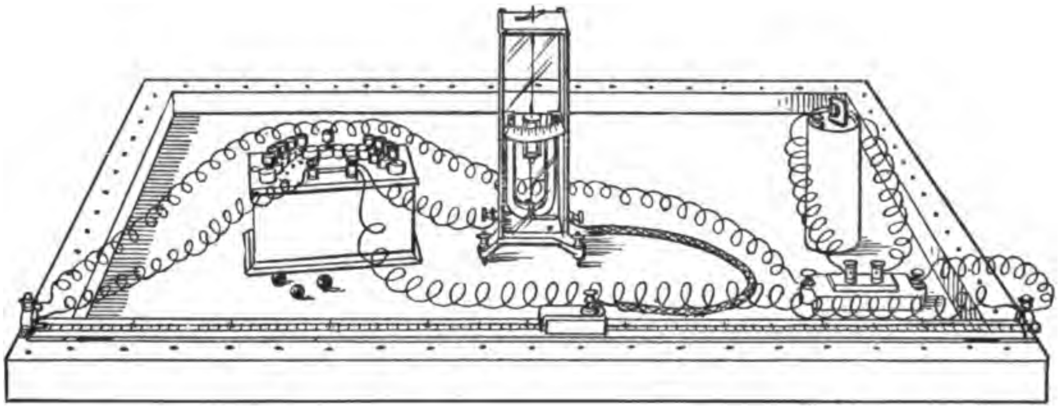
If any three of these resistances are known, the fourth may be calculated from Equation (4).

In the slide-wire bridge one of the branches is a straight wire of uniform cross-section stretched over a scale, and the two resistances in that branch are proportional to the lengths of the two parts into which a sliding contact connected with the bridging wire divides it.

What to use. Wheatstone slide-wire bridge. (This may consist of a German silver wire having a diameter of .3 mm. to .5 mm., and stretched over a meter stick laid across a general utility board between two peg-and-collar clamps.) D'Arsonval galvanometer. Resistance box. Dry cell. Commutator or key slider. Four 50 cm. connecting wires; the one joining the galvanometer and slider should be flexible like lampcord. Four connecting wires as short as possible to join the resistance box and the unknown resistance to the apparatus; these should be of thick wire in order that their resistances may be neglected. German silver wires about .2 to .4 mm. in diameter. Spools of insulated wire of known lengths, sizes, and materials, provided with binding posts or connectors, will be required in the optional part.

To compare the resistance of a wire with that of another.

What to do. (1) Connect the parts of the apparatus as shown in the figure, making the contacts bright and tight. Be sure that the plugs of the resistance box are firmly inserted. Use as the unknown resistance R_s one of the coils of a set of resistance spools or a piece of German silver wire prepared as follows: Cut off about 110 cm. of the wire and measure its diameter with micrometer calipers. If it is insulated, strip off about 5 cm. of the insulation from each end. Make a sharp kink about 5 cm. from one end, and, stretching the wire rather tightly over the meter stick, make another kink exactly one meter from the first kink. Connect this wire so that the kinks just touch the binding posts, thus leaving one meter of the wire, the resistance of which is to be determined.



General Utility Board and Accessories for Wheatstone Bridge

(2) Close the cell circuit by the key or commutator, and press the slider on the middle point of the slide-wire. If the apparatus is properly set up, the galvanometer pointer will move to one side or the other. Take out the 100-ohm plug from the resistance box, and again note the deflection. If it is in the same direction as before, the unknown resistance is less than 100 ohms. In the former case, take out more and more of the plugs until an opposite deflection is obtained. In the latter case, replace the 100-ohm plug, and take out the 10-ohm plug. Should the deflection be in the same direction as at first, the unknown resistance is greater than 10 ohms; so try the intermediate plugs, such as 50, 20, and so on. Should the deflection be the opposite to what it was at first, replace the 10-ohm plug and remove the one-ohm plug. The procedure of finding what resistance is to be inserted by taking out plugs is similar to that of finding the weight of a body by taking out the weights from the box or block and placing them upon the balance pan. Time will be saved by taking out the plugs in a systematic manner. When the resistance is found to the nearest whole ohm, try the plugs that represent the tenths of an ohm, always making contact at the middle of the slide-wire.

(3) When the unknown resistance and the known resistance have been made as nearly equal as possible by taking out the plugs of the resistance box, move the sliding contact along the wire until no deflection is obtained, when the battery circuit and then the galvanometer circuit is closed. To locate accurately the position where no current passes through the galvanometer, find the point on the slide-wire where there is just a perceptible movement of the pointer in one direction, and then find another point where

the pointer moves by the same amount in the opposite direction. Read these positions to tenths of a millimeter and take their average. This point divides the straight wire into two portions the resistances of which are proportional to their respective lengths.

(4) Let the lengths of the two portions of the straight wire be designated by a and $100-a$, respectively. Since a is directly proportional to R_2 and $100-a$ to R_4, if the known resistance be denoted by R_1 and the unknown resistance by R_3, the value of R_3 may be computed by means of the equation:

$$\frac{a}{100-a} = \frac{R_2}{R_4} = \frac{R_1}{R_3},$$

or

$$R_3 = \frac{100-a}{a} R_1$$

(5) Determine the resistance of another German silver wire of the same diameter and a greater length, or of the same length and a greater diameter. Connect the two wires in parallel and measure their joint resistance. Denote the resistances of each of the German silver wires by r_3 and r_3', and their joint resistance by R. Compute the value of the expression $\frac{1}{r_3} + \frac{1}{r_3'}$, and find the percentage of difference between it and the value obtained for R. The reciprocal of resistance is conductance. How does the conductance of two wires joined in parallel compare with the conductances of each of the wires?

(6) *Optional.* Find the resistances of the spools of wire provided.

TABULATION

Kind of Wire	Length of Wire	Diameter of Wire	a	$100-a$	R_1	R_3
	cm.	cm.	cm.	cm.	ohms	ohms

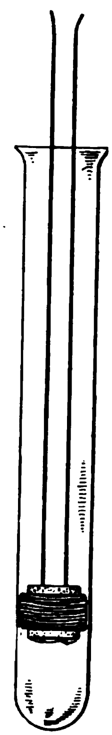
EXPERIMENT LXII

TEMPERATURE COEFFICIENT OF RESISTANCE

Temperature Coefficient. The resistance of most metals increases with rise of temperature. If R denotes the resistance of a wire at the temperature t, and R' its resistance at the temperature t', the temperature coefficient of resistance is defined to be the change of resistance per unit of resistance per degree of temperature:

$$\text{Temperature coefficient} = \frac{R' - R}{R'(t' - t)}.$$

What to use. Wheatstone bridge. Dry cell. D'Arsonval galvanometer. Beaker of water mounted upon a ring stand. Burette clamp. Bunsen burner. Wide 6-in. test tube. Thermometer thrust through a cork somewhat wider than the test tube. Temperature coil. This consists of about 10 m. of fine insulated copper wire, to the ends of which are attached (tightly wrapped, or better, soldered) two terminals of thick copper wire about 20 cm. long. The terminals are passed lengthwise through a cylindrical cork, and the fine wire is doubled together at its middle and wrapped around the cork. Two double connectors. Kerosene.



To find the temperature coefficient of resistance of copper.

What to do. (1) Place the coil nearly at the bottom of the test tube and bend the terminals over the edge of the tube. Cover the coil with kerosene and insert a thermometer so that its bulb is entirely covered by the kerosene. Support the test tube by means of the clamp in the beaker, and connect the terminals by means of the double connections to the Wheatstone bridge in the place of the unknown resistance R_3.

(2) Find the resistance of the temperature coil at the temperature of the room, as read off on the thermometer immersed in the kerosene.

(3) Heat the water to gentle boiling and, as soon as the temperature is constant, determine the resistance of the heated coil.

(4) Compute the temperature coefficient and the per cent of error.

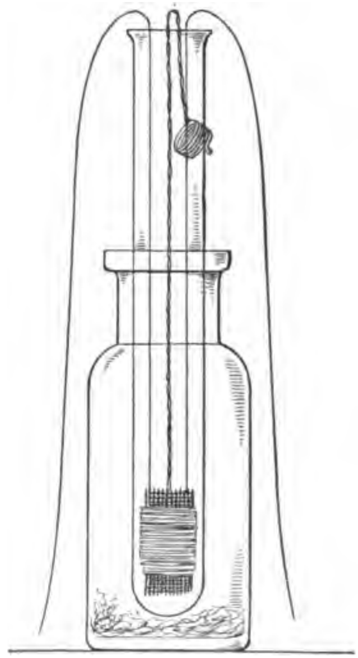
TABULATION

t'	Higher temperature	°
t	Lower temperature	°
	Change of temperature $t' - t$	°
R'	Resistance at t'	ohms
R	Resistance at t	ohms
	Change in resistance	ohms
	Temperature coefficient	
	Accepted value	.00388
	Per cent of error	%

EXPERIMENT LXIII

HEATING EFFECTS OF CURRENTS—JOULE'S LAW

What to use. Source of constant current giving about 2 amperes; four fresh dry cells (connected in series) or their equivalent will do. Tangent galvanometer or ammeter. Resistance box. Commutator or key. Thermometer thrust through a cork. 6-in. test tube set in a wide-mouthed bottle having a little cotton in the bottom. Connecting wires. Double connector. Watch. Kerosene. Cold water. Resistance coils made as follows: Cut off about 5 m. of insulated copper wire (No. 34 B. and S. gauge). Put a small ink spot on the wire about 30 cm. from one end. Measure off from this spot one meter of the wire, and mark this length with a second ink spot. Make a third ink spot about 30 cm. from the second, and measure off 3 m. of the wire, marking this length also. Wind the three meters around a hollow cylinder of wire gauze about 3 cm. long and 1 cm. in diameter, fastening the end by passing it through the meshes of the gauze. Loop the unmeasured middle portion of the wire, and wind the one-meter length on the gauze cylinder. Fasten the ends and the loop so that the coils cannot unwind. Strip the insulation from the ends of the wire and from the middle of the loop. By making connections at the ends of the wire, a current may be passed through both coils, while by making connections at the middle of the loop and either end of the wire, a current may be sent through either coil. The ratio of the resistances of the separate coils is as 3 : 1, and that of the two coils in series to either coil, as 4 : 1 or as 4 : 3, according to the connections.



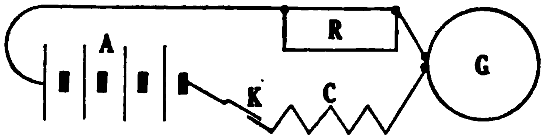
To ascertain what effect the strength of current and the resistance of a conductor have upon the transformation of electrical energy into heat.

What to do. (1) Push the coils to the bottom of the test tube with the free ends and the loop projecting from its mouth. Pour into the test tube just enough kerosene to cover the coils. Insert the thermometer and adjust its cork, which should be too large for the test tube so that the bulb nearly reaches to the bottom of the tube.

(2) Connect the apparatus as in the diagram (p. 160), using the 4-turn winding of the galvanometer and the one-meter coil. Close the circuit and note the deflection of the pointer. If it is less than 60°, add another cell or two; if it is greater than 60°, remove plugs from the resistance box, that is, introduce resistance into the circuit. It is not essential that the deflection be exactly 60°; any deflection between 50° and 60° will answer. If an ammeter is used, try to make the current strength as nearly as possible equal to 2 amperes.

(3) Lift out the test tube without disturbing the connections, and set it into cold water until the thermometer registers about 15°. Wipe off the tube and set it back again into the bottle.

(4) Stir the kerosene with the thermometer, and read the temperature to tenths of a degree. Note the time on the seconds-hand of the watch, and close the circuit. Read the deflection at both ends of the pointer but do not reverse the current. Break the circuit at the expiration of two minutes. Stir the kerosene until the temperature ceases to rise, reading the highest temperature shown by the thermometer. What is the amount of change in temperature?



A, Battery; K, Key; C, Coils; R, Resistance Box; G, Galvanometer

(5) Look up the tangent of the average of the angles of deflection, and then find the angle that has a deflection one-half as large.

(6) Connect the two coils in series as in (2), close the circuit, and adjust the strength of the current by introducing resistance from the box into the circuit, until the deflection is equal to that calculated in (5). How does the strength of the current, and the lengths and the resistances of the portions of the wire immersed in the kerosene, now compare with those used before?

(7) Repeat (3) and (4) with the joined coils and the weaker current. How does the change in temperature now found compare with that observed in (4)? What right have you to assume that the amounts of heat generated in each case are proportional to the rises of temperature? How do these amounts of heat compare? In one case you have half the current strength and four times the resistance, while in the other case you have twice the current strength and one-fourth the resistance. In what relation does the square of the current strength stand to the resistance of the circuit when the amount of heat evolved remains constant? How do the results of this experiment prove the validity of the C^2rt-law.

TABULATION

Source of current ....

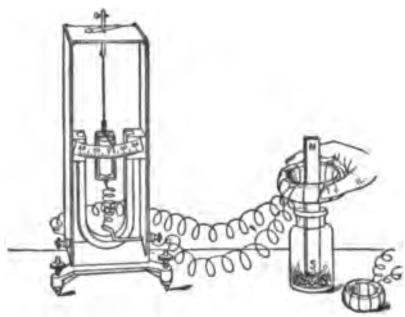
	One-Meter Coil	Four-Meter Coil
Time current passed	sec.	sec.
Deflection, east end....................................	°	°
Deflection, west end	°	°
Average deflection	°	°
Tangent of average deflection		
Initial temperature	°	°
Final temperature	°	°
Change of temperature	°	°

EXPERIMENT LXIV

INDUCED CURRENTS

Current Induction. Whenever any body capable of carrying a current of electricity is moved in a magnetic field in such a way that the number of lines of force that are intercepted or cut by the body is changed, a current of electricity is set up in the body. Such a current lasts only as long as there are lines of force being cut by the conductor. The energy required for the production of these *induced currents* is derived from the mechanical energy expended in moving the conducting body across the lines of force of the magnetic field; mechanical energy is then transformed into electrical energy.

What to use. D'Arsonval galvanometer. Bar or U-magnet with its poles marked. Two or more dry cells or their equivalent. Commutator. Compass. Two 30 cm. and one 10 cm. connecting wires. Tumbler of water to which a couple of drops of sulphuric have been added. Strip of zinc. Two flat coils of insulated wire about .3 mm. thick; one (the *primary coil*) has an internal diameter of about 3 cm. and 100 to 200 turns; the other (the *secondary coil*) has an internal diameter such that it can be slipped over the primary coil, and has 500 to 700 turns. About 50 cm. of the ends of the wire of each coil are left unwound to serve as leads in making connections with the galvanometer or battery. The coils are tied together with cord or wrapped around with tape, and one side or face is marked. Short cylinder of soft iron (an iron weight will do) fitting within the primary coil. Wide-mouthed bottle with a little cotton in the bottom to serve as a support for the magnet.



To study the induction of currents by magnets.

What to do. (1) Join the two long connecting wires to the galvanometer. Pressing the bared end of the wire connected with the left terminal of the galvanometer against the zinc strip, dip the strip as well as the end of the other wire into the dilute acid, and note the direction (right or left) in which the galvanometer pointer turns. The current of such a cell is so weak that there is no danger of its injuring the instrument. Since you make the current flow from the right terminal through the galvonometer to the left terminal and note the direction of the deflection of the pointer, you will be able in future work to tell from the galvanometer deflection the direction in which a current sent through the galvanometer is flowing. Distinguish these directions by the words — right and left.

If the poles of the magnet are not marked, determine them by the aid of a compass, and mark them with chalk or with gummed paper.

(2) Substitute the leads of the secondary coil for the connecting wires. Holding the magnet vertically with its N-pole uppermost, thrust the coil quickly over it down

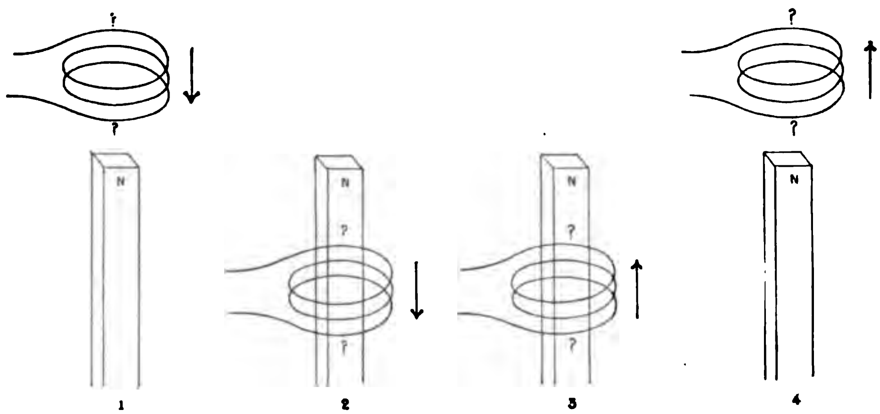
to about the middle of the magnet, and keep it there until the pointer comes to rest. Note the direction and the amount of deflection of the pointer. Should the pointer move off the scale, place the coil over the magnet more slowly. What is the direction of the momentary current induced in the coil? This induced current makes the coil (solenoid) a temporary magnet. (See Experiment LII (11).) Is the lower side of the coil made a N-pole or a S-pole as it approaches the N-pole of the magnet?

(3) Quickly slip the coil from the magnet, after making sure that the pointer has returned to its original positon. How does the amount and the direction of the deflection compare with that found in (2)? Does the lower side of the coil become a N-pole or a S-pole while it is moving away from the N-pole of the magnet?

(4) Repeat (2) and (3) with the S-pole of the magnet uppermost.

(5) Mark on the diagram or a copy of it N's and S's where the ?'s are, in order to indicate the polarity of the coil when it is moving in the directions shown by the arrows through each of the four positions. Is the polarity of the coil always such as to assist or to oppose the motion?

(6) Repeat (2), (3), and (4) with the coil turned upside down. What effect upon



the direction (with respect to the magnet) of the induced current does the inversion of the coil have?

(7) Put the coil around either of the poles of the magnet, and rotate it and move it sidewise to and fro, but not up or down; that is, move the coil parallel to the lines of force. What is the effect upon the galvanometer needle? Does a sidewise or a rotary motion increase or decrease the number of lines of force cut by the coil?

(8) Move the coil very slowly down over one of the poles. How does the amount of deflection compare with that observed when the coil is moved rapidly? Move the coil quickly down nearly to but not over the pole in such a way that only a part of the lines of force are cut by it; that is, move the coil through a weak part of the magnetic field. How does the amount of deflection compare with that observed when the coil is moved quickly through most of the lines of force surrounding the pole?

(9) Substitute the coil with the smaller number of turns for the secondary coil. Thrust it over one of the poles of the magnet with the same speed as you did with the secondary coil. How do the amounts of deflection of the two coils compare? The amount

of deflection is a measure of the induced E. M. F. What three items have you observed to have an influence upon the value of the induced E. M. F.?

II. *To study the induction of currents by currents.*

(10) Connect the lower part of the commutator with the primary coil, and the upper part with the cells joined in series. Connect the galvanometer with the secondary coil.

(11) Hold the primary coil vertically in the magnetic meridian and hold a compass at its center. Close the circuit and from the deflection of the compass ascertain the direction of the battery current flowing through the coil. (See Experiment LII (12).) Make sure of your conclusion by reversing the current and testing again.

(12) With the primary circuit closed, quickly lay the secondary coil over the primary coil. How does the direction of the induced current compare with the direction of the inducing current? Lift up the secondary coil quickly. How do the directions of the induced and the inducing currents compare? Is an N- or an S-pole on the upper side of the primary coil? What pole appears at the lower side of the secondary coil when it is brought down upon the primary coil? When it is lifted up?

(13) Repeat (11) with the primary circuit reversed.

(14) Repeat (11) and (12) with the iron cylinder within the primary coil. What effect does the iron core produce?

(15) With the primary circuit open, lay the secondary coil around the primary coil. Close the primary circuit, and note the direction and the amount of the deflection. How do the directions of the induced and the inducing currents compare? Break the primary circuit. Compare the direction and amount of the deflection with that observed at make. What pole appears at the lower side of the secondary coil when the primary circuit is closed? When it is opened? Is the current in the secondary coil caused by the electromagnetism of the primary coil, or by the changes in its electromagnetism? Does the induced current magnetize the secondary coil in such a way as to assist or to oppose the changes in the electromagnetism of the primary coil?

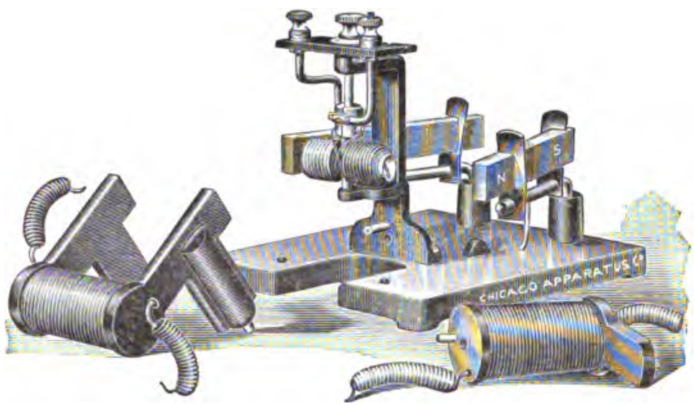
(16) Place the cylinder of soft iron within the coils and repeat (13). Account for the difference in the amounts of deflection as compared with those observed in (13).

EXPERIMENT LXV

MOTOR AND DYNAMO

Electric Motor. The electric motor consists essentially of an electromagnet, called the ***armature,*** that can rotate between the poles of a fixed permanent or a second electromagnet, named the ***field magnet.*** The armature is provided with a ***commutator*** by means of which the direction of the current sent through it, and hence its polarity, are reversed at regular intervals during one rotation. After the armature has turned, because of the action between its poles and those of the field magnet, through a certain angle (180° in the case of the motor used here), the direction of the current is reversed; the poles of the armature are thereby also reversed, with the result that the action between the two sets of poles is reversed. The armature does not, however, swing back into its original position, because its inertia carries it on far enough for the reversed action to make it continue its rotation. How this is accomplished will be shown by the experiment.

What to use. Perfected St. Louis motor. Electromagnet field pieces, Nos. 1 and 2. Resistance box. Commutator.* Spring contact key. Compass. Five 30 cm. connecting wires. D'Arsonval galvanometer. Two or three dry cells.



To study the construction and action of a motor and a dynamo.

What to do. (1) Connect a cell with the upper part of the reversing key, and join the lower part in series with the armature of the motor and the resistance box.

(2) Swing the bar magnets around until their opposite poles are close to the ends of the iron core of the armature. Adjust the brushes so that they bear lightly and yet make good contact upon the split-ring of the armature. Why does the armature tend, when slightly displaced, to set itself with its core along a straight line connecting the poles of the magnets? What difference in behavior do you observe when the armature is rotated through 180° and then displaced as above? Swing aside the magnets and see if the armature tends to assume any particular position. Has the armature a polarity of its own due to residual magnetism?

(3) Swing the magnets up to the armature again, close the circuit, and gently tap the armature in order to make it turn slightly first in one direction and then in the other. At the same time shift the brushes, by manipulating the knob at the top of the

* The mercury commutator will be called a *reversing key* in this experiment to prevent its being confused with the commutator of the motor.

motor, in one direction and the other until the armature, when given a start, spins around rapidly. Find by repeated trials the position of the brushes where the armature spins most smoothly and rapidly.

(4) Swing one of the magnets aside. What is the effect upon the speed of rotation? Then swing the other magnet aside. What effect?

(5) While the magnets are swung aside, close the circuit, and test the polarity of the armature by bringing up a compass to the ends of the iron core. Should the magnetic field be strong enough to reverse the poles of the magnetic needle, weaken the field by introducing into the circuit a few ohms resistance by means of the resistance box. Rotate the armature by hand slowly. What happens to the needle of the compass when the brushes pass over the insulating slits from one segment of the commutator to the other? Rock the armature in such a way as to cause the brushes to make contact with one and then the other of the segments. How does the compass needle behave?

(6) Reverse the circuit and repeat (5).

(7) With the circuit open and the magnets in the position of (2), set the armature parallel to the magnets, that is, perpendicular to the lines of force of the field. Send a current through the armature in such a direction that a N-pole will be developed in the end of the armature facing you. Toward which pole of which bar magnet does the N-pole of the armature turn? Point out two attracting and two repelling forces that act together in making the armature rotate.

(8) Repeat (7) with the current reversed so that the S-pole of the armature is facing you. How do you account for the change in the direction of rotation?

(9) Turn each of the magnets end for end so as to reverse the direction of the lines of force of the field. Repeat (7) and (8). How do you account for the differences observed compared with what was observed in (7) and (8)? What effect does reversing both the polarity of the field and the direction of the current through the armature have upon the direction of rotation?

(10) While the motor is running at full speed, introduce into the circuit resistance, a few tenths of an ohm at a time. What effect is produced? How may the rate of rotation of a motor be regulated?

(11) Swing the bar magnets back, and mount one of the electromagnet field pieces on the motor base. Join the terminals of the field piece in series with a key and a dry cell. Close the circuit through the field magnet and ascertain by means of the compass the polarity of the pole pieces. Reverse the direction of the current by interchanging the cell connections (or a reversing key may be used) and ascertain the polarity.

(12) Repeat (3) with the electromagnet field instead of a permanent magnet field. How does the position of the brushes compare with their position as found in (3)? What is the position of the brushes in each case with respect to the direction of the lines of force of the field?

(13) (*Optional.*) Repeat (12) with the other electromagnet field piece.

(14) Remove the key and the dry cell. Connect one terminal of the field magnet with a binding post of the reversing key, and the other terminal with the binding post of the motor that was connected with the just mentioned binding post of the reversing key. The field magnet is thus placed in series with the armature?

(15) Close the circuit and shift or adjust the brushes in order to make the motor run well. While the motor is running, quickly reverse the current. Why is it that the direction of the rotation remains the same?

(16) Connect the terminals of the field magnet with the binding posts of the motor, to which are also attached the wires leading to the reversing key. The field magnet is now on a shunt circuit. Repeat (15).

(17) Swing the bar magnets up to the poles of the armature, and adjust the position of the brushes so as to make the motor run evenly and rapidly. Substitute a D'Arsonval galvanometer for the reversing key and cell. Note the direction in which the galvanometer pointer turns when the armature is rotated (*a*) to the right; (*b*) to the left. Change the magnets end for end, and note the direction of the pointer when the armature is rotated as before. Wherein does a dynamo differ from a motor?

EXPERIMENT LXVI

THE TELEGRAPH

What to use. Sounder. Key. Relay. One or two dry cells. Resistance box. Connecting wires. For the optional part, gravity cells, stands and clamps, meter sticks, insulators (small wide-mouthed bottles), and a line wire are needed.

To study the construction and action of the instruments of a telegraphic system.

What to do. (1) Connect the key, the sounder, and the dry cell in series. With the circuit closer of the key open, press down the lever for an instant. Note how the two clicks are produced, one at make and one at break. In the Morse alphabet a single instantaneous stroke of the lever is called a dot. A short dash is made by holding down the lever for as long a time as it takes to make three dots, and a long dash for as long a time as is taken to make five dots. *Breaks* are the intervals between dots and dashes in the same letter. Manipulate the key so as to produce some of the letters given in the Morse alphabet.

A ·–	**H** ····	**O** · ·	**U** ··–
B –···	**I** ··	**P** ·····	**V** ···–
C ·· ·	**J** –·–·	**Q** ··–·	**W** ·––
D –··	**K** –·–	**R** · ··	**X** ·–··
E ·	**L** —	**S** ···	**Y** ·· ··
F ·–·	**M** ––	**T** –	**Z** ··· ·
G ––·	**N** –·		

(2) With the lever up, push the circuit-closer under it. What evidence is there that the circuit is thereby closed? Where is the insulation that keeps the circuit open when the lever is up and the circuit-closer pushed away from it? Trace the circuit through the key (*a*) when the circuit-closer is open and the lever depressed; (*b*) when the circuit-closer is closed and the lever up. Trace the circuit through the sounder, turning it over in order to see how the connections are made.

(3) Put a resistance box in the series circuit and, by taking out the plugs, introduce just enough resistance to weaken the current to such an extent that the armature does not click when the key is pressed down. Record the resistance introduced and add to it the resistance of the sounder itself (marked upon the instrument).

(4) Connect the binding posts of the relay that lead to the electromagnets in series with the key, resistance box, and the same cell (or battery) as was used with the sounder. With no resistance inserted from the box, depress the key and note the action of the armature. How does the movement of the armature make and break the circuit (local circuit) connected with the other two binding posts of the relay? Why is one of the set screws between which the tip of the armature plays provided with an insulating end? Trace out the circuit through the relay.

(5) Introduce enough resistance into the line circuit by taking out the plugs of the resistance box to just make the relay stop working. Add to this resistance that of the relay itself (marked on the instrument). Why is it that a relay can work when a sounder cannot, even if the line resistance with the relay is much greater than with the sounder?

(*Optional.*) *To set up and operate a short distance telegraph line.*

(6) Fasten a meter stick vertically in the clamp of the stand and run a wire (line wire) up from the table to the top of the meter stick, tying it fast with twine. (A small wide-mouthed bottle may be put over the end of the stick to serve as an insulator.) Continue the line wire over to another table on which is a similar " telegraph post." Connect one end of the line wire to the positive pole of a gravity cell at one table and the other end to the negative pole of a gravity cell at the second table. Connect the other poles of the cells in series with a key and a sounder, and a wire wrapped around a gas or water pipe, the return circuit thus being through the earth. (How?)

(7) Close the switch at one table and manipulate the lever at the other. Which sounder clicks? When an operator is sending a message, should the circuit-closer at his station be open or closed? Should the circuit-closer at the intermediate stations as well as at the receiving station be open or closed? Why is the gravity cell the best cell for telegraphic service?

(*Optional.*) *To set up and operate a long distance telegraph line.*

(8) Substitute relays for the sounders of (6) and (7), connecting in the line the binding posts that lead to the electromagnets. In the local circuit put the sounder and dry cells. Operate the system as in (7).

APPENDIXES

APPENDIX A

TABLE I

METRIC SYSTEM

Only those units that have an abbreviation given in parenthesis are in common use.

LENGTH	MASS	VOLUME	NOTATION
Kilometer (km.)	Kilogram (kg.)	Kiloliter	1000.
Hectometer	Hectogram	Hectoliter	100.
Decameter	Decagram	Decaliter	10.
METER (m.)	GRAM (g.)	LITER (l.)	1.
Decimeter	Decigram	Deciliter	.1
Centimeter (cm.)	Centigram (cg.)	Centiliter	.01
Millimeter (mm.)	Milligram (mg.)	Milliliter	.001

TABLE II

EQUIVALENTS

Metric to English

1 cm.	=	.3937 inches
1 m.	=	39.37 inches
1 km.	=	.6214 miles
1 cm.^{2}	=	.155 square inch (in.^{2})
1 cm.^{3}	=	.061 cubic inch (in.^{3})
1 l.	=	1.057 quarts
1 g.	=	15.44 grains
1 g.	=	.0353 oz.
1 kg.	=	2.204 lbs.

English to Metric

1 inch (in.)	=	2.54 cm.
1 foot (ft.)	=	30.48 cm.
1 mile (mi.)	=	1.609 km.
1 in.^{2}	=	6.45 cm.^{2}
1 in.^{3}	=	16.39 cm.^{3}
1 quart (qt.)	=	.946 l.
1 grain (gr.)	=	64.8 mg.
1 ounce	=	28.35 g.
1 lb.	=	.4536 kg.

TABLE III

MENSURATION RULES

π = ratio of the circumference of a circle to its diameter.
r = radius; h = altitude; d = diameter.

Circumference of a circle .... $= 2\pi r$
Area of a circle .... $= \pi r^2$
Surface of a sphere .... $= 4\pi r^2$
Volume of a sphere ...... $= \frac{1}{6}\pi d^3$ .. $= \frac{4}{3}\pi r^3$
Volume of a right cylinder $= \frac{1}{4}\pi d^2 h$ .. $= \pi r^2 h$

TABLE IV

Densities (grams per cubic centimeter)

Aluminum	2.7	Lead	11.35
Beeswax	.96	Marble	2.7 to 2.8
Brass	8.4 to 8.6	Mercury, 0° C.	13.596
Copper	8.8 to 8.9	Paraffin	.91
Cork	.14 to .23	Platinum	21.5
Glass, crown	2.5	Quartz	2.65
Glass, flint	3.0 to 3.5	Silver	10.45
Gold	19.3	Steel	7.8 to 7.9
Ice	.917	Tin	7.3 to 7.4
Iron, wrought	7.8 to 7.9	Vulcanite	1.20
Iron, cast	7.1 to 7.2	Zinc	6.9 to 7.0

TABLE V

Surface Tensions (grams per centimeter)

Acetone at 20°	.0243	Toluene at 20°	.0292
Alcohol at 20°	.0225	Water at 20°	.0721
Benzene at 20°	.0309	Water at 30°	.0705
Ether at 20°	.0169	16% salt solution at 20°	.0775

TABLE VI

Coefficients of Linear Expansion

Aluminum	.000023	Glass	.0000086
Brass	.0000189	Iron and steel	.0000121
Copper	.0000173	Platinum	.0000088

TABLE VII

Melting Points

Acetamide	82° C.	Naphthalene	80 C.
Acetanilide	115	Sodium thiosulphate ("hypo")	45 to 50
Beeswax	60 to 64	Thymol	44
Diphenylamin	54	Paraffin	45 to 50
Menthol	42		

TABLE VIII

Boiling Points

Acetone	56° C.	Ether	35° C.
Alcohol	78	Mercury	357
Carbon tetrachloride	76	Water	100

TABLE IX

Specific Heats

Alcohol	.62	Iron	.112
Aluminum	.21	Lead	.031
Brass	.094	Mercury	.033
Copper	.095	Toluene	.54
Glass	.2	Turpentine	.43
Kerosene	.5 to .6	Zinc	.094

APPENDIX B

TABLE OF SINES AND TANGENTS

Angle	Sine	Tangent	Angle	Sine	Tangent	Angle	Sine	Tangent
1°	*.017*	.017	**31°**	*.515*	.601	**61°**	*.875*	1.804
2	*.035*	.035	**32**	*.530*	.625	**62**	*.883*	1.881
3	*.052*	.052	**33**	*.545*	.649	**63**	*.891*	1.963
4	*.070*	.070	**34**	*.559*	.675	**64**	*.899*	2.050
5	*.087*	.087	**35**	*.574*	.700	**65**	*.906*	2.145
6	*.105*	.105	**36**	*.588*	.727	**66**	*.914*	2.246
7	*.122*	.123	**37**	*.602*	.754	**67**	*.921*	2.356
8	*.139*	.141	**38**	*.616*	.781	**68**	*.927*	2.475
9	*.156*	.158	**39**	*.629*	.810	**69**	*.934*	2.605
10	*.174*	.176	**40**	*.643*	.839	**70**	*.940*	2.747
11	*.191*	.194	**41**	*.656*	.869	**71**	*.946*	2.904
12	*.208*	.213	**42**	*.669*	.900	**72**	*.951*	3.078
13	*.225*	.231	**43**	*.682*	.933	**73**	*.956*	3.271
14	*.242*	.249	**44**	*.695*	.966	**74**	*.961*	3.487
15	*.259*	.268	**45**	*.707*	1.000	**75**	*.966*	3.732
16	*.276*	.287	**46**	*.719*	1.036	**76**	*.970*	4.011
17	*.292*	.306	**47**	*.731*	1.072	**77**	*.974*	4.331
18	*.309*	.325	**48**	*.743*	1.111	**78**	*.978*	4.705
19	*.326*	.344	**49**	*.755*	1.150	**79**	*.982*	5.145
20	*.342*	.364	**50**	*.766*	1.192	**80**	*.985*	5.671
21	*.358*	.384	**51**	*.777*	1.235	**81**	*.988*	6.314
22	*.375*	.404	**52**	*.788*	1.280	**82**	*.990*	7.115
23	*.391*	.424	**53**	*.799*	1.327	**83**	*.993*	8.144
24	*.407*	.445	**54**	*.809*	1.376	**84**	*.995*	9.514
25	*.423*	.466	**55**	*819*	1.428	**85**	*.996*	11.430
26	*.438*	.488	**56**	*.829*	1.483	**86**	*.998*	14.300
27	*.454*	.510	**57**	*.839*	1.540	**87**	*.999*	19.080
28	*.469*	.532	**58**	*.848*	1.600	**88**	*.999*	28.640
29	*.485*	.554	**59**	*.857*	1.664	**89**	*.999*	57.290
30	*.500*	.577	**60**	*.866*	1.732	**90**	*.000*	∞

Fractions of angles are more conveniently expressed in decimals than in minutes and seconds. To find the tangent of an angle denoted by a decimal number such as, for example, 22°.7, proceed as follows:

$$\tan 22° = .404 \; ; \tan 23° = .424$$
$$.424 - .404 = .020$$
$$.7 \times .020 = .014$$
$$\tan 22°.7 = .404 + .014 = .418$$

Likewise, the sine of 22°.7 is found thus:

$$\sin 22° = .375 \; ; \sin 23° = .391$$
$$.391 - .375 = .016$$
$$.7 \times .016 = .0112$$
$$\sin 22°.7 = .375 + .011 = .386$$

The angle of a tangent, such as .418, that is intermediate to two tangents given in the table is found as follows:

$$.404 = \tan 22° \; ; .424 = \tan 23°$$
$$.418 - .404 = .014$$
$$.424 - .404 = .020$$
$$.014 \div .020 = .7$$
$$.418 = \tan 20°.7$$

A similar procedure will give the angle of a sine that lies between two sines given in the table.

APPENDIX C

Apparatus

In this list are included the pieces that will have to be bought ready made for the satisfactory performance of the first 65 experiments. The omission of such pieces as are used but seldom will reduce the total cost of a set considerably, and there will still be enough pieces for the performance of a satisfactory number of experiments. The number in parenthesis gives the cost per experiment. The number of experiments in which a piece can be used may be found by dividing its price by the cost per experiment. To illustrate, the price of the general utility board is $5.00, and it is used in fifteen experiments. Hence the cost per experiment is 33 cents.

1 Meter stick (.01)	$ .21
1 Circular disk (.25)	.25
1 Graduated tube (.11)	.60
1 Vernier calipers (.43)	2.15
1 Micrometer calipers (.33)	2.95
1 Steel ball, ½ in. (.06)	.06
1 Perfected balance (1.00)	11.50
1 Set, universal weights (.11)	1.75
1 Thermometer, −10 to 110° C. (.03)	.35
3 2000-g. spring balances (.17)	1.05
1 Stand, 24 in. rod, two rings (.03)	.45
1 Burette clamp (.02)	.35
1 General utility board (.31)	5.00
10 General utility board pegs (.03)	.30
1 Hydrometer tube (.25)	.25
1 Hydrometer jar, 2 × 18 in. (.30)	.90
1 Aluminum cylinder (.30)	.30
1 Surface tension apparatus (.75)	.75
1 Boyle's law apparatus, 1st method (.75)	1.50
1 Boyle's law tube (.30)	.30
1 Hare's balancing columns apparatus (.80)	.80
1 Lever holder (.25)	.25
2 Iron balls, 1½ in., drilled for suspension (.05)	.20
1 Wood ball, 1½ in., drilled for suspension (.07)	.07
1 Single pulley (.20)	.20
1 Double pulley (.35)	.35
1 Flask, 500 cm.^{3} (.03)	.18
1 Wire gauze (.005)	.05
1 Brass tube, 44 × ½ in. (.20)	.40
3 General utility board peg-and-collar clamps (.21)	1.05
1 General utility board calipers clamp (.35)	.35
1 Y-tube (.04)	.08
2 Pinchcocks (.10)	$ .30
1 Jacketing tube for Boyle's law apparatus (.50)	.50
2 Beakers, 400 cm.^{3} (.08)	.42
2 General utility board pulleys (.15)	.30
1 Reflection plate (.05)	.05
1 Refraction plate (.25)	.25
1 Prism, glass (11)	.22
1 Concave mirror (.25)	.25
1 Pin support for optical bench (.04)	.08
3 Lens supports (.10)	.30
1 Biconvex lens, 10 cm. focus (.05)	.15
1 Biconvex lens, 25 cm. focus (.08)	.08
1 Color top (.08)	.08
1 Compass (.02)	.15
1 Soft iron rod, 15 cm. (.04)	.10
1 U-magnet (.08)	.30
2 Dry cells (.05)	.46
1 Perfected commutator (.07)	.75
1 Electric bell (.40)	.40
1 Push button (.02)	.10
1 Perfected tangent galvanometer (1.19)	9.50
1 Oxyhydrogen voltameter (1.00)	1.00
1 Perfected resistance box (.96 .)	4.95
2 General utility board slip-over clamps (.20)	.20
2 General utility board electric pegs (.15)	.30
1 Perfected D'Arsonval galvanometer (.49)	2.48
1 Contact block or slider (.15)	.45
1 Daniell cell (.15)	.45
1 Primary coil (.50)	.50
1 Secondary coil (.75)	.75
1 Perfected St. Louis motor with two electromagnet field pieces (3.30)	3.30
	$64.07

Accessory Apparatus

This list includes the accessory pieces of apparatus that can be made by the instructor or student from stock or from materials easily obtained anywhere. Directions for their preparation are given in the Manual or in the Teacher's Handbook. The figure in brackets is the number of the experiment in which the apparatus is first used.

1 Prism, hardwood, 2 × 1 in. [7]	.07
1 Indicator, 32 cm. [7]	.05
1 Vertical scale, 20 cm., on base [7]	.15
1 Lead sinker with hook [12]	.12
1 Friction block [22]	.15
1 Stirrer [28]	.10
1 Microscope support [43]	.20
1 Telescoping tubes [44]	.20
1 Glass plate [45]	.05
1 Black cardboard screen with slits and colored strips [46]	.40
1 Glass plate, any color [46]	.10

1 Test tube and slit cork [31]	.10
1 Steam calorimeter [33]	.75
1 Steam trap [33]	.18
1 Calorimetric body support [33]	.25
1 Calorimetric body drip pan [33]	.25
1 Suspension for calorimetric body [33]	.25
1 Boiling point tube [32]	.30
1 Translucent screen [42]	.10
1 Iron screen with perforated slide [42]	.75
1 Watch spring [47]	.05
1 Sheet of iron, copper, lead, zinc, each [47]	.10
1 Iron washer [49]	.05
1 D'Arsonval coil and suspension [52]	.50
1 U-magnet support [52]	.20
1 Temperature coil [62]	.30
2 Double connectors [62]	.20
1 Resistance coil [63]	.35
1 Soft iron cylinder [64]	.10

Additional Apparatus

This list contains pieces which, while not essential, are desirable. They will not give any better results than the pieces already listed, but will enable the instructor to diversify the work.

Vulcanite cylinder [3]	\$ .35
Micrometer calipers, friction head, 25 mm. [4]	4.95
Dividers [6]	.22
Mirror scale and support [6]	1.10
Jolly balance [6]	7.75
Improved Jolly balance	22.50
2-kg. universal weight [36]	.70
5-kg. universal weight [36]	1.35
Lever multiplying device [7]	.50
Micrometer screw, friction head, mounted on heavy base [7]	2.70
Specific gravity bottle, 25 $cm.^3$ [9]	.30
Pipette, 20 $cm.^3$ [9]	.20
Specific gravity bob, glass [12]	.25
Commercial hydrometer [14]	.40
Base for Boyle's law apparatus [16]	.50
Stop-watch [21]	6.50
Pendulum clamp [21]	.50
Inclined plane, complete [23]	1.30
Inclined plane car [23]	.90
Aluminum tube, $44 \times \frac{1}{2}$ in. [26]	1.05
Apparatus "A" [26]	1.75
Tripod for apparatus "A" [26]	.25
Perfected linear expansion apparatus [26]	2.95
Copper ball, $1\frac{1}{2}$ in., drilled for suspension [28]	.50
Zinc ball, $1\frac{1}{2}$ in., drilled for suspension [28]	.35
Calorimeter, brass, 600 $cm.^3$ [28]	.45
Calorimeter, nickel-plated copper, double with fiber ring [28]	2.25
Cooling through change of state apparatus filled with acetamide or diphenylamin and with slit cork [31]	\$ .50
Rubber hammer [34]	.10
Steelyard, metric, 50 kg. [35]	2.50
15-kg. spring balance [36]	1.60
Tension screw for spring balances [36]	.40
Electric lamp and support [41]	.75
Reading glass [42]	.45
Electric color top [45]	.90
Gelatine film, mounted on glass, per color [46]	.15
4-in. ignition tube [48]	.15
Crucible tongs [48]	.27
Magnet board [49]	.40
Blue print paper, 24 sheets [49]	.25
Demonstration cell [50]	.50
Perfected contact key [53]	.45
Perfected volt-ammeter [54]	9.75
Gravity cell [55]	.80
Leclanché cell [55]	.45
Wheatstone bridge with potentiometer attachment [61]	2.00
High resistance coil for D'Arsonval galvanometer [59]	.50
Set of unknown resistance coils [61]	3.00
Telegraph key [66]	1.75
Sounder [66]	2.50
Relay [66]	3.00